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THESIS

IN

ACUSTICA APPLICATA E ILLUMINOTECNICA

NOISE MAPPING OF HIGHLY TRAFFICKED ROADS OF THE PROVINCE OF BOLOGNA ACCORDING TO D.Lgs. 194/2005

CANDIDATE:

Giulia Parantelli

SUPERVISOR:

Chiar.mo Prof. Massimo Garai

ASSISTANT SUPERVISOR:

Ing. Luca Barbaresi

Ing. Dario Fattori

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ABSTRACT

L'Unione Europea riconosce il rumore come una delle maggiori fonti di inquinamento ambientale. Negli ultimi anni la Comunità Europea ha sottolineato la necessità di mitigare tale inquinamento attraverso azioni in concerto tra tutti gli Stati Membri. La mappatura acustica rappresenta lo strumento per la raccolta di informazioni tramite indicatori armonizzati e mappe di rumore che evidenziano i valori di tali indicatori, il superamento dei limiti e il numero di persone o abitazioni esposte. Il D.Lgs. 149/2005 in attuazione della Direttiva Europea 2002/49/CE definisce le metodologie, gli indicatori e i tipi di risultati da trasmettere alla Comunità Europea.

La tesi presenta il lavoro effettuato per la mappatura acustica delle strade della Provincia di Bologna. Coerentemente ai requisiti relativi alle fase di invio dati DF4 e DF8, così come indicato dalla Direttiva, sono state considerate le parti dell'infrastruttura stradale di pertinenza della Provincia di Bologna che si trovano al di fuori dell'agglomerato urbano e che sono caratterizzate da un volume traffico superiore ai tre milioni di veicoli annui. A livello pratico è stata considerata un area di buffer di 1 km rispetto ad ogni asse stradale.

Per la realizzazione delle mappe sono stati utilizzati gli indicatori armonizzati L_{den} e L_{night} poiché, nonostante essi siano diversi dagli indicatori nazionali vigenti, è consentita la conversione dei limiti.

La mappatura acustica prevede la creazione di un modello digitale che comprende il modello del terreno, gli edifici, l'infrastruttura stradale, la definizione delle classi d'uso e dei coefficienti di assorbimento delle superfici. Per la creazione del modello digitale del terreno è stata posta particolare attenzione a modellare, anche manualmente, tutti gli elementi che possono interferire con la propagazione del suono come rilevati e trincee, strutture di sostegno per ponti ecc. I dati utilizzati per la creazione del modello del terreno, la definizione geometrica degli edifici e l'assegnazione delle classi d'uso provengono prevalentemente dal database topografico regionale (DBTR), i dati demografici necessari all'allocazione degli abitanti sono stati estrapolati dai dati ISTAT del 2011, mentre per i dati meteorologici si è fatto riferimento al toolkit 17 della Good Practice Guide non essendo disponibile uno standard nazionale. L'infrastruttura stradale è stata definita secondo i dati del sistema informativo territoriale della Provincia.

I dati di traffico, necessari alla modellazione della sorgente, sono stati reperiti da diverse fonti come la Regione, la Provincia e l'Anas. E' stato necessario un confronto ed una analisi, riportate dettagliatamente nell'elaborato, per ottenere il numero di transiti e la distribuzione nei periodi giorno, sera, notte, le velocità e le percentuali di veicoli pesanti.

Il metodo di calcolo utilizzato è indicato nell'allegato 2 del D.Lgs. 194/2005 ed è il metodo francese NMPB-Routes-96 (SETRA-CERTU-LCPC-CSTB). Tale metodo è stato implementato nel software SoundPLAN . Nell'elaborato sono esplicitate le caratteristiche principali del metodo di calcolo e del software.

Per verificare la risposta del modello è stata eseguita una calibrazione puntuale. Lo scopo era quello di verificare che, per dati di traffico affidabili, la risposta del modello fosse accettabile. La calibrazione ha previsto una coppia di brevi misurazioni relative a qualche giorno. La differenza ottenuta tra valori misurati e valori simulati è stata ritenuta accettabile nel contesto di studio globale di un'area vasta, consentendo la validazione del modello.

I risultati sono stati ottenuti sotto forma di mappe di rumore per gli indicatori L_{den} e L_{night} e in forma di mappe di esposizione, in cui per ogni livello di rumore a intervalli di 5 dB è indicato il numero di abitanti esposti. Le mappe si riferiscono ad ogni arco stradale così come richiesto da normativa.

Per avere una visione globale di tutta l'area di studio, le informazioni sono state combinate tramite somme logaritmiche ottenendo la sovrapposizione degli effetti per le aree attigue a più archi stradali. Tale operazione permette l'individuazione diretta delle aree dove i livelli di rumore sono più elevati.

Conclusa la mappatura acustica è stato scelto di approfondire l'analisi tramite la realizzazione di mappe di priorità. Tali mappe sono costruite sulla base di indici di priorità che combinano il livello di rumore con il numero di persone esposte e sono necessarie per la pianificazione e l'assegnazione delle priorità di intervento che caratterizzano i piano d'azione. L'indice di priorità ECU_{den} è stato preferito a quello indicato dalla normativa italiana precedente "indice di priorità P" poiché meno arbitrario e di più facile implementazione. E' stata creata una mappa per l'area relativa a tre archi stradali della SP 253 San Vitale. L'individuazione delle aree più critiche ha permesso di avanzare proposte di tipo qualitativo per interventi di riduzione e abbattimento del rumore. Le tipologie di intervento e i criteri da adottare nella scelta di esse sono elencati in appendice.

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1 INTRODUCTION

The European Community has stressed the importance of achieving a common understanding to deal with the environmental noise through community actions of the Member States. This implies the use of harmonized indicators and specific information regarding the values of indicators, the exceedance of limits and the number of people and dwellings exposed to noise.

The D.Lgs. 149/2005 [10] in compliance with the European Directive 2002/49/EC [1] defines methodologies, noise indicators and types of outputs required.

In this dissertation the work done for the noise mapping of highly trafficked roads of the Province of Bologna will be reported. The study accounts for the environmental noise generated by the road infrastructure outside the urban agglomeration of Bologna. Roads characterized by an annual traffic greater than three millions of vehicles will be considered.

The process of data collection and validation will be reported, as long as the implementation of the calculation method in the software and the procedure to create and calibrate the calculation model. Results will be provided as required by the legislation, in forms of maps and tables.

Moreover results regarding each road section accounted will be combined to gain a general understanding of the situation of the overall studied area.

Although the understanding of the noise levels and the number of people exposed is paramount, it is not sufficient to develop strategies of noise abatement interventions.

Thus a further step will be addressed: the creation of priority maps as the basis of action plans for organizing and prioritizing solutions for noise reduction and abatement.

Noise reduction measures are reported in a qualitative way in the annex and constitute a preliminary research.

2 RELEVANT LEGISLATION

2.1 NOISE AND NOISE PROTECTION

Noise could be defined as: «audible sound that causes disturbance, impairment or health damage». [18] European Commission Working Group - Expert Panel on Noise (EPoN), Good practice guide on noise exposure and potential health effects, EEA Technical Report n. 11/2010. [18] Many studies prove the correlation between noise exposure and effects on health. Effects can vary from feeling discomfort, stress and sleep disturbance, cardiovascular effects, up to, in very extreme cases, mortality.

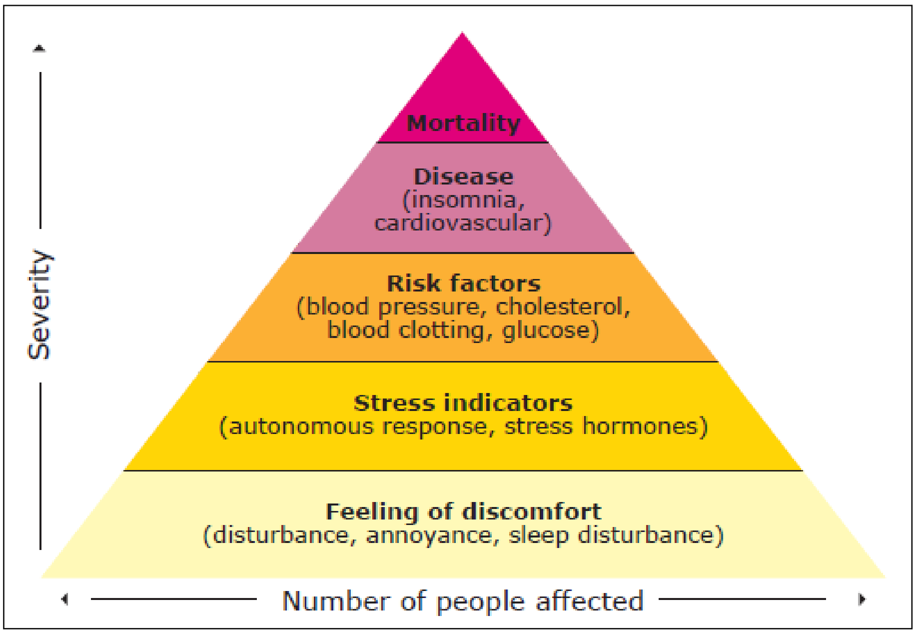

Figure 2.1- Relationship between noise exposure and effects on health [18]

It is evident that, in order to obtain a high level of health and environmental protection, protection against noise should be taken into account.

The awareness of the noise problem induced many States to promote their own noise control systems. Systems present differences, but in general they all rely on the correlation between noise exposure, expressed through noise indicators, and thresholds of these indicators values, that have been determined in order to preserve health and wellbeing. Thus, noise limit values are at the basis of noise control systems.

Studies indicate noise as one of the major environmental problem in Europe. To deal with the noise problem and complement the actions of Member States, the European Community promoted the Directive 2002/49, also called the European Noise Directive (END) [1].

Effect	Dimension	Acoustic indicator *	Threshold **	Time domain
Annoyance disturbance	Psychosocial, quality of life	L_{den}	42	Chronic
Self-reported sleep disturbance	Quality of life, somatic health	L_{night}	42	Chronic
Learning, memory	Performance	L_{eq}	50	Acute, chronic
Stress hormones	Stress Indicator	L_{max} L_{eq}	NA	Acute, chronic
Sleep (polysomnographic)	Arousal, motility, sleep quality	$L_{max, indoors}$	32	Acute chronic
Reported awakening	Sleep	$SEL_{indoors}$	53	Acute
Reported health	Wellbeing clinical health	L_{den}	50	Chronic
Hypertension	Physiology somatic health	L_{den}	50	Chronic
Ischaemic heart diseases	Clinical health	L_{den}	60	Chronic

Note: * L_{den} and L_{night} are defined as outside exposure levels. L_{max} may be either internal or external as indicated.
** Level above which effects start to occur or start to rise above background.

Figure 2.2- Example of indicators thresholds and correlated health effects [18].

2.2 EUROPEAN LEGISLATION

The European Directive 2002/49/EC [1], relating to the assessment and management of environmental noise, has the purpose of preventing and reducing harmful effects of the exposure to environmental noise. The END underlines the importance of complementing the action of Member States through a Community action that aims to achieve a common understanding of the noise problem with comparable criteria for the collection and the report of data. Thus, common methods of assessment of the acoustic pollution situation and noise exposure, are prescribed.

For this purpose the END introduces new definitions, evaluation methods and harmonized indicators, as day-evening-night noise indicator L_{den} and night-time indicator L_{night}.

Noise mapping is the main tool for the determination and the description of the noise exposure. The noise mapping procedure is defined as well as different maps types containing all types of information required. Data reported are: the values of significant indicators, the exceedance of limits and the number of people or dwellings exposed to certain values of noise indicators. Another important tool described in the END is the action plan. Action plans have the purpose of managing noise effects where it is necessary and preserving environmental noise quality where it is good;

During all the process information to the public is prescribed. Public should be aware of environmental noise exposure level and its effects.

2.3 ITALIAN LEGISLATION

2.3.1 D.Lgs 149/05

The END has been acknowledged by the D. Lgs. 149/05 [10] *"Attuazione della direttiva 2002/49/CE relativa alla determinazione e alla gestione del rumore ambientale"*, legislative decree 149/05, implementation of Directive 2002/49/EC relating to the assessment and management of environmental noise.

The D.Lgs. 149/05 defines competences and procedures to:

- the elaboration of noise maps and strategic noise maps to assess the exposure to environmental noise;
- the elaboration and the adoption of action plans to avoid and reduce environmental noise where it is necessary, especially where exposure levels could have harmful effects on human health, and to preserve quiet areas;
- ensure the information to the public and its involvement regarding environmental noise and relative effects;

The D.Lgs 149/05 is applied for:

- agglomerations with more than 100000 residents;
- major civil airports, that is to say civil airports with more than 50000 movements per year;
- major railways, with more than 30000 transits per year;
- major roadways with more than 3000000 vehicles per year.

For each case specific deadlines for data production are established according to the number of people or the annual traffic.

Noise indicators are those defined in the END, day-evening-night noise indicator L_{den} and night-time indicator L_{night}, reference periods instead, are not compulsory and member States can adopt their own.

The D. Lgs. 149/05 defines:

- day period of 14 hours (06-20)
- evening period of 2 hours (20-22)
- night period of 8 hours (22-06)

The Italian State should deliver data in the prescribed form and by the deadlines to the European Community. The Legislative Decree 149/05 represents the compliance of the national legislation to the EC principles and it is the first step through the process of harmonization.

2.3.2 OTHER NATIONAL LAWS.

The National regulatory framework is quite complex, hence here is reported in summary.

D.P.C.M. March 1st 1991 [2], introduces for the first time in Italy maximum limit values of noise exposure indoor and outdoor.

Law October 26th 1995, n. 447 [3], "*legge quadro sull'inquinamento acustico*", framework law on noise pollution, establishes general principles regarding the safeguard of indoor and outdoor ambient from noise pollution. The law allocates responsibilities to State, Regions, Provinces and Municipalities. A series of decrees implement the general principles:

D.M. October 31st 1997 [4], prescribes the methodologies to airport noise measurement and procedures to adopt in order to reduce airport noise; it defines criteria to identify limiting areas for airport activities and introduces the airport noise indicator LVA. For airports daily period is from 06 a.m. to 11 p.m.

D.P.C.M. November 14th 1997 [5], introduces noise zoning and it states new limit values of noise exposure indoor and outdoor. New noise limit values are defined: absolute limit values of noise immissions and emissions and limit values of differential noise immissions, attention values and quality values. Noise values are expressed according to the $L_{A,eq}$, continuous equivalent sound level corrected with weighting curve A. $L_{A,eq}$ is referred to day period from 06 a.m. to 11 p.m. and to night period from 11 p.m. to 06 a.m.

D.M. March 16th 1998 [6], defines assessment and measurement of noise pollution implementing article 3 subsection c) of Law 447/95.

D.P.R November 18th, n.459 [7], sets the regulations to prevent and reduce noise generated by railways infrastructures, and superficial metro infrastructures, excluding tram lines and cable railways. It defines the width of strips pertinent to the railway infrastructures, where specific absolute limit values of noise immissions apply.

D.M. November 29th 2000 [8], indicates technical criteria that Societies and authorities of public transportation services should apply for the provision of plans for noise containment and abatement.

D.P.R. March 30th 2004, n. 142 [9], establishes the regulations to prevent and reduce noise generated from road infrastructures. It also defines the width of strips pertinent to the road infrastructures, where specific absolute limit values of noise immissions apply.

2.3.3 REGIONAL LEGISLATION

Regional Law May 9th 2001, n. 15 [11] "*Disposizioni in materia di inquinamento acustico*", regulations on noise pollution. The Emilia Romagna Region implements article 4 of L.447/95. The law states rules for the protection of health and the safeguard of outdoor and indoor environment from noise sources.

D.G.R. October 9th 2001, n. 2053 [12], defines criteria and conditions for noise zoning of the territory according to article 2 subsection 3 of the Regional Law 15/01.

D.G.R. January 21st 2002, n.45 [13], defines the competences for local authorities to release authorization for temporary noisy activities according to article 11 subsection 1 of the Regional Law 15/01.

D.G.R. April 14th 2004, n. 673 [14], sets technical criteria for the drafting of the documentation of noise impact prevision and noise climate evaluation according to the Regional Law 15/01.

2.4 METHODOLOGY REFERENCES

In addition to the legislation reported in this chapter, other methodology references have been taken into account. Here they are reported in summary:

- Good Practice Guides of the European Commission [16],[17];
- guidelines as the Practitioner handbook for local noise actions plan elaborated for European project Silence [19];
- guidelines for noise mapping and strategic noise mapping published by UNI [20],[21],[22];
- guidelines of the Emilia Romagna Region for noise mapping [23].

3 AREA OF INTEREST

The END requires different obligations with corresponding deadlines to the drafting of data (data flows). The summary of deadlines and corresponding data flow is reported in the table below.

DEADLINES	OBLIGATIONS	DF AND UPDATES
01/18/2004	Art. 10-1: EC report to EP and Council on noise sources The Commission must submit to the European Parliament and the Council a report containing a review of existing Community measures relating to sources of environmental noise	
07/18/2004	Art. 14: transposition MS must bring into force laws, regulations, and administrative provisions necessary to comply with the END.	
06/30/2005	Art. 7-1: report to EC on areas covered by 1st noise maps & action plans MS must inform the Commission of agglomerations with more than 250 000 inhabitants, major roads which have more than six million vehicle passages per year, major railways which have more than 60 000 train passages per year and major airports within their territories.	DF1 Mandatory every 5 years
07/18/2005	Art. 4: report to EC on competent authorities designated by MS MS must make available to the Commission and the public information on bodies and authorities responsible for strategic noise maps, action plans and related data collection. Art. 5-4: report to EC on limit values MS must communicate to the Commission information on any relevant limit values (in force or under preparation) of noise emitted by road traffic, rail traffic, air traffic around airports and industrial activity sites as well as explanation about their implementation.	DF2 Possible at any time
01/18/2006	Art. 1-2: EC legislative proposals to EP and Council on noise sources The Commission shall submit to the European Parliament and the Council appropriate legislative proposals on noise reduction of main sources of environmental noise (road, rail, aircraft etc.).	DF3 Possible at any time

06/30/2007	Art. 7-1: 1st round of noise maps MS must ensure that strategic noise maps showing the situation in the preceding calendar year have been made and, where relevant, approved by the competent authorities, for all agglomerations with more than 250 000 inhabitants and for all major roads which have more than six million vehicle passages per year, major railways which have more than 60 000 train passages per year and major airports within their territories.	
12/30/2007	Art. 10-2: report to EC on 1st round noise maps MS must ensure that information from strategic noise maps as referred in annex VI of the END are sent to the Commission.	DF4 Mandatory every 5 years
07/18/2008	Art. 8-1: 1st round of action plans MS must ensure that the competent authorities have drawn up action plans for (a) places near the major roads which have more than six million vehicle passages a year, major railways which have more than 60 000 train passages per year and major airports; (b) agglomerations with more than 250 000 inhabitants.	Mandatory every 5 years
12/31/2008	Art. 7-2: report to EC on areas covered by the END MS must inform the Commission of all agglomerations, major roads, major railways and major airports falling under the scope of the END.	DF5 Possible at any time
01/18/2009	Art. 10-2: report to EC on 1st round action plans MS must ensure that the information from summaries of action plans as referred in annex VI (noise control programs that have been carried out in the past and noise measures in place) are sent to the Commission.	DF6 No update
01/18/2009	Art. 10-2: report to EC on 1st round action plans MS must ensure that the information from summaries of action plans as referred in annex VI (action plans related to data in annex IV) are sent to the Commission.	DF7 Mandatory every 5 years
07/18/2009	Art. 10-3, 10-4: EC database and reports The Commission must set up a database of information on strategic noise maps in order to facilitate the compilation of the report referred to in article 11 and other technical and informative work.	Mandatory every 5 years
07/18/2009	Art. 11: EC reporting The Commission must submit to the European Parliament and the Council a report on the implementation of the Directive.	

06/30/2012	Art. 7-2: 2nd round of noise maps MS must ensure strategic noise maps showing the situation in the preceding calendar year have been made and, where relevant, approved by the competent authorities for all agglomerations and for all major roads and major railways within their territories.	Mandatory every 5 years
12/30/2012	Art. 10-2: report to EC on 2nd round noise maps MS must ensure that information from strategic noise maps as referred in annex VI of the END are sent to the Commission.	DF8 Mandatory every 5 years
07/18/2013	Art. 8-2: 2nd round of action plans MS must ensure that competent authorities have drawn up action plans for all agglomerations and for all major roads and major railways within their territories.	DF9 Mandatory every 5 years
01/18/2014	Art. 10-2: report to EC on 2nd round action plans MS must ensure that the information from summaries of action plans asreferred in annex VI are sent to the Commission.	DF10

Table 3.1- Deadlines relating to the implementation of the END [1]

For areas outside the urban agglomerations data flows DF4 and DF8 correspond to noise maps for major roads, major railways and major airports. In the studied case that corresponds to:

- DF4 roads with more than 6000000 vehicles per year;
- DF8 roads with 3 to 6 millions of vehicles per year.

Thus, the studied areas cover by roads of the Province of Bologna outside the urban agglomerations characterized by more than 3 millions of total transits of vehicles per year.

Roads that fall into this selection are subdivided in road sections according to their annual traffic flow and their geometrical characteristics. This results into 27 different road sections belonging to 17 provincial roads.

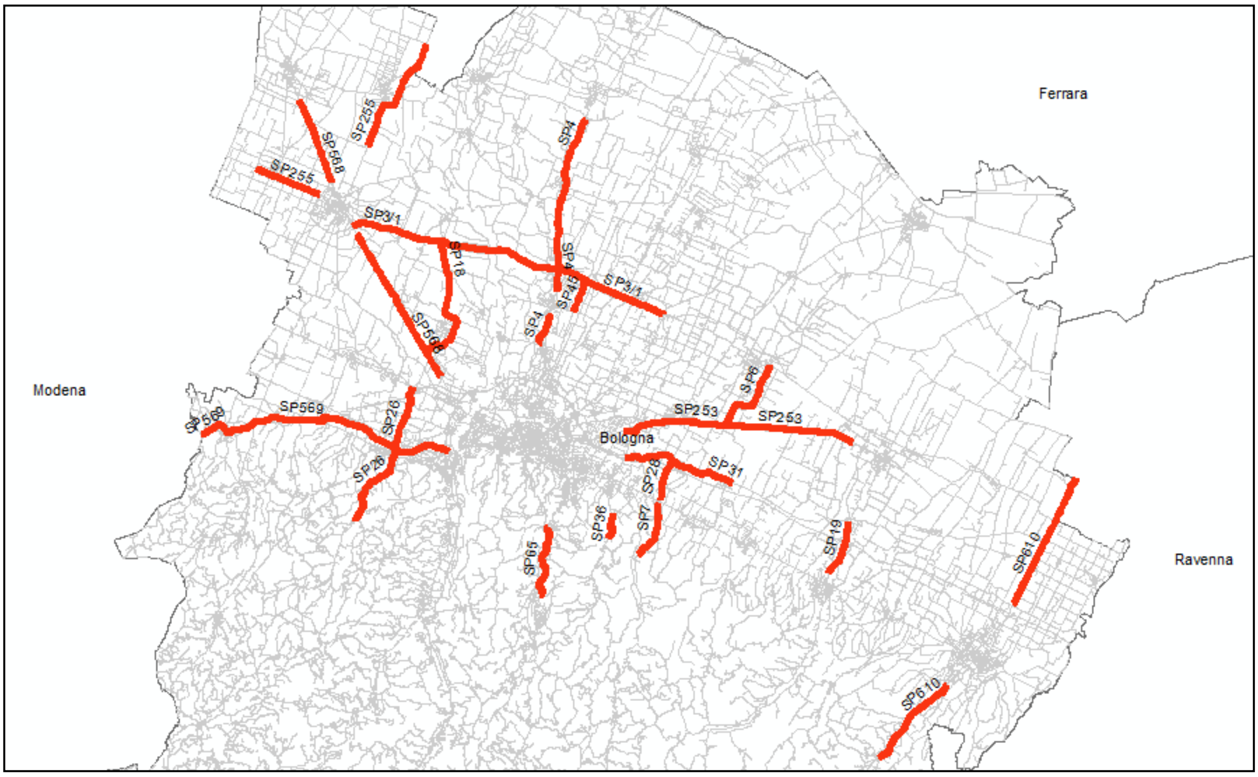

Figure 3.1- Studied area: major roads of the Province of Bologna

According to the END, the buffer area that should be mapped starts from the road middle line include all those areas where L_{den} > 55 dB. It can be proven that if L_{den} > 55 dB, L_{night} > 50 dB. This requires a preliminary screening that is in general quite complex. Thus, another method has been applied: it has been considered a precautionary buffer area of 1 km from each side of the infrastructure including the start and the end heads. For this type of infrastructure it is certain that after 1 km L_{den} < 55 dB.

In practice the digital model has been created to cover buffer areas of 2 km. This is a even more precautionary solution, in facts, it allows to refine the simulation for areas on the edge of the buffer of 1 km, considering the contribution of elements just outside the smaller buffer. Then, mapping has been performed over buffers of 1 km.

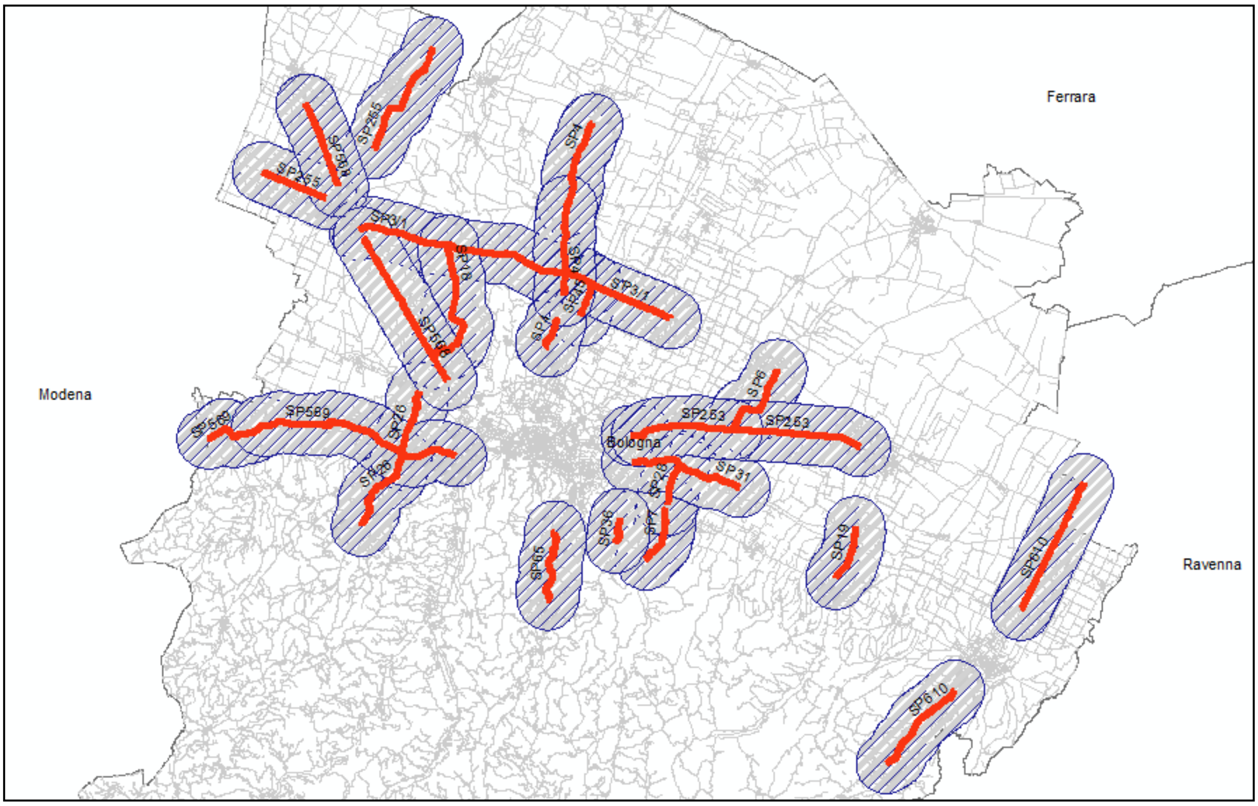

Figure 3.2- Studied area: buffers of the major roads of the Province of Bologna

4 NOISE MAPPING

Noise mapping is «the presentation of data on an existing or predicted noise situation in terms of a noise indicator, indicating breaches of any relevant limit value in force, the number of people affected in a certain area, or the number of dwellings exposed to certain values of a noise indicator in a certain area». [1]

According to the European Directive 2002/49/EC noise mapping is required in two cases:

- urban agglomerations with more than 100000 residents;
- sensitive areas outside the agglomerations, that is to say areas outside the agglomerations subjected to noise generated by transportation infrastructures.

Noise mapping for urban agglomeration is called "strategic noise mapping". The maps have the objective to determine or predict the overall noise exposure due to roads, railways, airports and industrial infrastructures including ports. Each noise map represents the effects of a single noise source.

Noise mapping for areas outside the agglomerations should account for roads, railways and airport infrastructures. Each noise source should be treated separately.

Noise maps can be represented by graphs, tables or electronic data. Maps typologies are chosen in function of the objective of the mapping. Further details will be provided in chapter 4.2.

4.1 NOISE INDICATORS

4.1.1 ITALIAN INDICATORS

The decrees D.M. October 31st 1997 [4] and D.P.C.M. November 14th 1997 [5], implementing the Law 447/95 [3], define respectively the airport noise indicators LVA and the continuous equivalent sound level corrected with weighting curve A, $L_{A,eq}$ for the other noise sources. $L_{A,eq}$ is referred to day period from 06 a.m. to 11 p.m. and to night period from 11 p.m. to 06 a.m.

Nowadays Member States might use national noise indicators for noise mapping, as long as data are not older than 3 years and suitable conversion to European indicators is performed. In UNI 11252 [20] conversion method and limits are specified. However, it has been chosen to use directly the European indicators L_{den} and L_{night}. This is due to the fact that the Law 447/95 [3] states that national limit values will be translated according to European limit values. Despite the fact that there is not a law implementing it yet, the conversion is possible. [23] The same approach have been used for the first cycle of the mapping of the Emilia Romagna Region and of the Bologna agglomeration.

4.1.2 EUROPEAN INDICATORS

The day-evening-night level L_{den} in decibels (dB) is defined by the following formula:

$$L_{den} = 10log\frac{1}{24}\left(14\cdot10^{\frac{L_{day}}{10}} + 2\cdot10^{\frac{(L_{evening}+5)}{10}} + 8\cdot10^{\frac{(L_{night}+10)}{10}}\right) \text{ in dB}$$

In which:

L_{den} is the A-weighted long-term average sound level determined over all the day-evening-night periods of a year;

L_{day} is the A-weighted long-term average sound level determined over all the day periods of a year;

$L_{evening}$ is the A-weighted long-term average sound level determined over all the evening periods of a year;

L_{night} is the A-weighted long-term average sound level determined over all the night periods of a year;

The day is 12 hours, the evening four hours and the night eight hours. The Member States may shorten the evening period by one or two hours and lengthen the day and/or the night period accordingly, provided that this choice is the same for all the sources and that they provide the Commission with information on any systematic difference from the default option.

This is the case of Italy that chose the day starting at 06.00 local time:

- the day is of 14 hours (06-20)
- the evening of 2 hours (20-22)
- the night of 8 hours(22-06)

A year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances.

The incident sound is considered, which means that no account is taken of the sound that is reflected at the façade of the dwelling under consideration (as a general rule, this implies a 3 dB correction in case of measurement). This means that both the noise reflection on the ground and the multiple reflections at least at the first order of reflecting objects like buildings, noise barriers, embankments etc. have to be considered. Instead the reflection on the façade of the building considered as noise receiver should be:

- included if a noise map is generated;
- neglected if an exposure map is generated;
- neglected subtracting 3 dB to the values measured at the receiver if a noise map is generated through measurements. [23]

The height of the Lden assessment point depends on the application:

in the case of computation for the purpose of strategic noise mapping in relation to noise exposure in and near buildings, the assessment points must be 4,0 ± 0,2 m (3,8 to 4,2 m) above the ground and at the most exposed façade; for this purpose, the most exposed façade will be the external wall facing onto and nearest to the specific noise source; for other purposes other choices may be made;

in the case of measurement for the purpose of strategic noise mapping in relation to noise exposure in and near buildings, other heights may be chosen, but they must never be less than 1,5 m above the ground, and results should be corrected in accordance with an equivalent height of 4 m;

For other purposes such as acoustical planning and noise zoning other heights may be chosen, but they must never be less than 1,5 m above the ground, for example for:

rural areas with one-storey houses;

the design of local measures meant to reduce the noise impact on specific dwellings;

the detailed noise mapping of a limited area, showing the noise exposure of individual dwellings.

4.1.3 SUPPLEMENTARY NOISE INDICATORS

The END [1] and consequently the D.Lgs. 194/05 [10] allows, for some cases in which it might be convenient, to use special noise indicators and related limit values, in addition to L_{den} and L_{night}. Here examples are reported:

- the noise source under consideration operates only for a small proportion of the time (for example, less than 20% of the time over the total of the day periods in a year, the total of the evening periods in a year, or the total of the night periods in a year);
- the average number of noise events in one or more of the periods is very low (for example, less than one noise event an hour; a noise event could be defined as a noise

that lasts less than five minutes; examples are the noise from a passing train or a passing aircraft);

- the low-frequency content of the noise is strong;
- LAmax, or SEL (sound exposure level) for night period protection in the case of noise peaks;
- extra protection at the weekend or a specific part of the year;
- extra protection of the day period;
- extra protection of the evening period;
- a combination of noises from different sources;
- quiet areas in open country;
- the noise contains strong tonal components;
- the noise has an impulsive character.

4.2 MAPS TYPOLOGIES

There are several typologies of noise maps, and each map is used for a specific purpose. The objectives of the map regard not only noise mapping, but also the drafting of the action plans. The legislation requires a minimum amount of maps, but other types of maps might be created. For example maps as intermediate step to get those required.

4.2.1 NOISE MAPS

Noise maps are representation of the present or predicted noise situation of a certain area. They can be obtained by monitoring campaigns or by models calculations. The graphical representation of noise maps is mandatory for major roads, major railways and major civil airports. This type of maps is obtained by the evaluation of the noise indicators L_{den} and L_{night} at a standard height of 4 meters from the ground level, in correspondence of points spaced on a grid or point of measurements properly spaced according to the context. The grid space should be < 10 m for urban agglomerations; < 30 m for extra-urban areas and < 100 m for airport areas. The calculation should take into account at least reflections of the first order.

Results should presented over chromatic maps where contour lines indicates level multiples of 5 [dB]. From these maps the area exposed to the different values of L_{den} is deduced. Moreover noise maps are necessary to built the other types of maps.

4.2.2 EXPOSURE MAPS

Exposure maps quantify, generally in a table representation, the number of residents and dwellings exposed to certain values of noise indicators. Through a specific weightning of people in specific buildings sensitive receivers like hospitals, rest houses, schools, can be taken into account. This type of information is useful to quantify inpact of noise levels on the population. However they are not directly regulated by law limits, that are expressed only with respect to noise limit values.

According to D.Lgs 194/05 [10] this type of map is compulsory. To obtain an exposure map it is necessary to start from noise maps and then allocate inhabitants from each building based on information on the population. To assign noise level to a building it is neccesary to consider the noise level of the most exposed façade. That implies the verification of the the direct component of the noise on each façade of the building. The Good Practice Guide [16] suggests a spatial resolution of 3 m on each façade. This technique allows also to identify a contingent quiet façade, that is to say a façade where the noise level is at least 20 dB lower with respect to the maximum noise level of the other façades of the building. The calculation points should be collocated at 1-2 m from the façades at elevation of 4 m from ground level. Reflection of at least first order generated by buildings and other obstacles should be accounted.

If the façade noise level is assigned from values obtained by a regular gridpoint , the maximum value among the values of the cells of the grid that intersecate the façade. A correction of -3 dB is necessary in this case to eliminate the component of the noise reflected by the receiver. The accuracy of this last method is affected by the grid dimension and by the correction on the reflected component.

4.2.3 CONFLICT MAPS

Conflict maps are graphical representations that show areas where the estimated noise values exceed the limit values. They are a useful tool to identify critical areas and plan interventions.

Conflict maps can account for all the noise sources or each source separately. They include all the cartographics elements of the noise maps and in particular they should indicate areas where conflicts arise.

Maps should include at least:

- spatial localization of receivers;
- typologies of receivers;
- localization of conflict areas in function of limit exeedance per intervals of 5 dB(A).

4.2.4 PRIORITY MAPS

Priority maps are graphical representations that show the most critical areas, where urgent mitigation is required. Critical areas are identified according to a criticality indicator that is function of the number of inhabitants or the number of dwellings exposed. These maps are not compulsory for D.Lgs. 194/05 but they are a necessary tool for the realization of action plans.

4.3 MINIMUM REQUIREMENTS

Minimum requirements for noise mapping and strategic noise mapping are listed in D.Lgs 194/05 [10]. Some requirement are reported below.

a) A noise mapping and a strategic noise map is the presentation of data on one of the following aspects:

- an existing, a previous or a predicted noise situation in terms of a noise indicator,
- the exceeding of a limit value
- the estimated number of dwellings, schools and hospitals in a certain area that are exposed to specific values of a noise indicator,
- the estimated number of people located in an area exposed to noise.

b) Noise maps and strategic noise maps may be presented to the public as:

- graphical plots,
- numerical data in tables,
- numerical data in electronic form.

c) Strategic noise maps for agglomerations shall put a special emphasis on the noise emitted by:

- road traffic,
- rail traffic,
- airports,
- industrial activity sites, including ports.

d) For the purposes of informing the citizen in accordance with Article 8 and the development of action plans in accordance with Article 4, additional and more detailed information must be given, such as:

- a graphical presentation,
- maps disclosing the exceeding of a limit value

- difference maps, in which the existing situation is compared with various possible future situations,
- maps showing the value of a noise indicator at a height other than 4 m where appropriate,
- the description of instruments and measurement techniques, as well as calculation models and relative accuracy.

e) Noise map and strategic noise maps should be created using a measurement height of 4 m, intervals of level of L_{den} and L_{night} of 5 dB as defined in attachment 6.

4.4 INFORMATION TO THE PUBLIC

Public should be informed about results of noise mapping and data should be reported in a clear and legible way, using tools like graphs and noise maps of various scale. It is important to underline that noise maps obtained according to END are global maps on wide scale and they might not be representative of specific local situations. Public should be informed also about instruments used and measurement techniques applied to the noise mapping as well as calculation models and relative accuracy.

Moreover public should be involved also in the action plan elaboration, through described consultation procedures described in article 8 of D. Lgs. 194/05. [10]

4.5 PROCESS PHASES

The noise mapping process can be schematized in the following phases, each phase implies the implementation of specific methodological processes related to the legislation.

1. collection of territorial and environmental data;
2. provision of the calculation system for the assessment of noise levels;
3. noise monitoring for model calibration;
4. elaboration of noise maps and strategic noise maps;
5. provision of results according to requirements;
6. information to the public.

4.6 PROCESS MANAGEMENT

The process management defined in D. Lgs. 194/05 [10] defines responsibilities of data production and presentation, information to the public, control of the technical operations and respect of deadlines.

The *Ministero dell'Ambiente e della Tutela del Territorio e del Mare*, the Environmental and Safeguard of Sea and Territory Departement, is the responsible of the transmission to the European Commission.

Noise mapping and action plans elaboration regarding major transportation infrastructures, inside and outside urban agglomerations, are required to infrastructure managers and to public transportation societies. Thus, each Province is responsible for roads of its competence. Nevertheless, for the first cycle of application, the Emilia Romagna Region had directly assigned and supervised the execution of the technical activities.

Data collection and control are assigned to:

- authority indicated by region for maps and action plans produced by managers of major infrastructures inside urban agglomerations;
- Region for the agglomerations and major regional infrastructures;
- Environmental Department for major transportation infrastructures concerning more Regions.

Deadlines are defined every 5 years, from 31/12/2006 for the first cycle, and from 31/12/2011 for the second cycle of noise mapping.

5 TERRITORIAL AND ENVIRONMENTAL DATA COLLECTION

5.1 INPUT DATA

The calculation model used for the noise mapping requires geo-referenced data in vector formats. Data collecting has a paramount importance for the quality and the validity of the results. Data regard:

- the localization and characterization of noise sources;
- the elevation profile of the ground;

the perimeters and ground factors of areas;

- the localization and characterization of the dwellings (perimeter, height, form);
- the localization and characterization of natural or artificial obstacles to the propagation;
- the distribution of the population in the residential dwellings;
- the meteorological conditions.

Data should refer to a specified reference year. In the studied case the reference year is 2011. However, in practice, available data often refer to other time periods, that are different for each type of data considered. Obtaining new updated data is impossible for budget and time constraints, so reference time period of the results refers to the reference time period of input data.

There are several data sources, as Municipalities, Provinces, Regions, ISTAT [26] (Italy's National Statistic Institute), and thus, some incompatibilities have been revealed. However, the main source of data has been the Regional topographic database (*DBTR*) of Emilia Romagna Region [27]. The database furnishes high quality and easy to access data.

Data should geo-referenced in the reference system ETRS89, projection UTM. When data obtained were in another reference system, proper conversions have been performed. Data obtained by DBTR are geo-referenced in the reference system ETRS89. Data obtained by the Province are geo-referenced in the cartographic projection GUASS-BOAGA. Conversion has been performed obtaining referencing in WGS84, projection UTM. In this case it has been chosen not to convert WGS84 in ETRS89 because this conversion would lead greater errors than those obtained leaving data without conversion.

The cartographic covering classes can have the following spatial characteristics:

GPT: punctual elements;

GLI: linear elements;

GPG: polygonal elements.

5.2 DIGITAL GROUND MODEL

For the construction of the ground digital model the following classes have been used:

- **DBTR 2008 - PQT_GPT - Elevation of point**. The following typologies of dimensioned points are included: dimensioned point isolated on the ground (on service area, circulation area, hydrographic area, open space, urban area or built area, on construction, at the bottom of edifices, for significant toponyms, on road, railway and hydrographic networks); points with elevation description of artificial structures, in general describing the elevation path of artificial structures extended above the ground level (for example the elevation of a structure, the roofing of buildings etc.).
- **DBTR 2008 - CLV_GLI - Contour line.** It corresponds to contour lines spaced by multiples of 5 m, refined for areas measured with scale factor 1000 or 2000 with contour lines spaced by multiples of 2.5 m, and where the slope is lower than 5% contour lines space by 1 m. They have to be projected without solution of continuity, in some cases with interpolation procedures where there are residential areas, roads, railways structures, rivers, lakes escarpments, rocks or other elements. Each line section can be uncertain or certain.
- **DBTR 2008 - AAI_GPG - Riverbed.** It represents the bed of a river.
- **DBTR 2008 - ARG_GPG - River bank**. It corresponds to embankments to contain and collect water. In this class are described the artificial and the natural banks, water regulation structures in correspondence of bodies of water (division of water containment for saltworks, paddy fields etc,) Moreover it includes draining ditches and drainage collectors in agricultural areas.
- **DBTR 2008 - CAN_GLI - Canal.** It is an artificial water flow realized with the insertion of a structure in natural or manmade materials for the purpose of collecting water, irrigating, draining, diversion, unloading of floods, hydro-electric energy production, navigation etc. It has usually low slope. It is modeled combining elements of water flow which have continuative characteristics and homogeneous direction, except for the case of underground water flow in which the water path is not known. It does not include meanders and secondary branches. The flow direction should be coherent with the direction of the stream, that can be determined on the basis of the elevation path of the ground. For canals that allows double flowing direction, a single direction should be assumed. The canal paths should be continuous and connect with

origin and delivery points in general with a natural hydrographic network or with artificial conducts including the midline of the hidden sections.

- **DBTR 2008 - FIL_GLI - Trees in row**. They are represented by a row in case the definition of a single tree is not possible, if the distance is smaller than 2 m, or in case there are rows of trees for cultivation not included in a tree cultivation area (agricultural area class).
- **DBTR 2008 - FIU_GLI - River.** Natural watercourse. Each element represents a superficial water body with flowing water naturally formed. The path is created through the combination of water elements, which presents continuity except for the cases where the except for the case of underground water flow in which the water path is not known. It can include meanders and secondary branches both at the beginning and at the end of the watercourse. The flow direction should be homogeneous.
- **DBTR 2008 - GAL_GPG - Tunnel.** Artwork with constant transversal section that allows continuous traffic, in general for roads or railways, through a mountain or an obstacle.
- **DBTR 2008 - EFE_GLI - Railway element.** It is the representation of the middle line of each track.
- **DBTR 2008 - MSD_GPG - Retaining wall.** It is a artwork to control the orography in order to make the territory safe and consistent with human activities.
- **DBTR 2008 - OSC_GLI - Edge of the escarpment**.
- **DBTR 2008 - PON_GPG - Bridge/viaduct/flyover**. Artwork to allow mobility from opposite sides of rivers, lakes, seas, flyover another object or flyover a hollowed area.
- **DBTR 2008 - SCA_GPG - Escarpment.** It is the definition of lines where a sudden change in slope occurs. This class includes natural and artificial escarpment, also due to geological movements like landslides. River and lake banks are not included.
- **DBTR 2008 - ZRC_GPG - Natural shape of the soil.** It is a description of the natural morphology of the soil. It includes rocky areas, isolated rocks with dimensions bigger than 2 m, pebbly areas, sandy areas, the entrance of caves or natural wells, gullies and ravines.
- **DBTR 2008 - ACS_GPG - Area for the circulation of vehicles.** It is the area designated for the circulation of vehicles, or in case of roads it is the area for public uses, open to traffic with width greater than 2.5 m. It can include highways, provincial roads, urban roads, local roads, forestry roads, rural roads, mule tracks and parking lots.

- ***PROTEZIONE AMBIENTE CIRCOSTANTE*, Surrounding environment protection.** It contains the planimetry of certain noise barriers located on the territory. It is obtained by the Informative Territorial System of the Province of Bologna [28].

5.2.1 PROCEDURE

The first draft of the digital ground model has been created in SoundPLAN using the class PQT_GPT of the Province of Bologna. The same class has been considered for the adjoining Municipalities where road section buffers felt out the Province limits. Adjoining Municipalities considered are: Nonantola, Massa Lombarda, Cento, Savignano sul Panaro and Riolo terme. The elevation path obtained has been implemented with CLV_GLI. These are the only classes that contain elevation information. Particular cases of incorrect elevation point have been corrected.

Subsequently the draft has been corrected with information obtained in the other classes and with the information available on the internet. For example from satellite images or images at ground level, the presence of additional noise barriers and embankments have been verified and, in case, taken into account manually. Manual modeling has been performed also for particular situations that have great impact on the noise propagation. This is the case of embankments, bridges and viaducts. The area of the model covers the buffer of 2 km from the middle lines of the road sections.

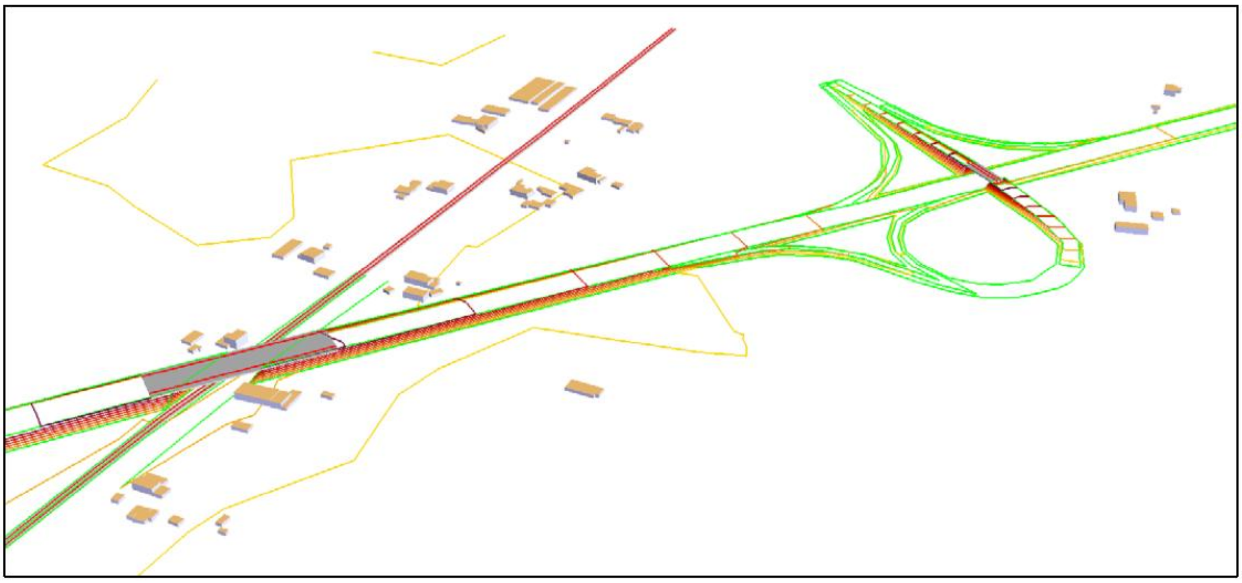

Figure 5.1- DGM corrected manually in case of particular elements as bridges and viaducts.

5.3 GROUND FACTORS

- **2008 Cartographic covering of land use - edition 2011.** It is a geo-references database in vector format that contains homogeneous groups of data that refer to land use classes. The database has been created from the one of 2003 with polygonal coverage. The reference scale is 1:25000. The information source are high definition Orthophotos (pixels of 50 cm) "AGEA 2008" colored (RGB). The classification covers 4 levels, from the first to the third the classification system used is that specified in the European project Corine Land Cover (CLC), while the fourth level is obtained referring to national specifications. In the database are included 83 different land use categories.. In the updated version of 2011 also the area of the Valmarecchia is included. The minimum area is 1.56 hectares and the minimum dimension is 75 m in general and 25 m for some particular categories.

5.3.1 PROCEDURE

To each land use the correspondent ground factor has been assigned according to the Toolkit 13 of the Good Practice Guide [16]. The area considered is the buffer of 2 km from each middle line of the road sections. The procedure is briefly reported below:

The toolkit 13 indicates for cases according to data availability. The land use classification corresponds to the second case and relative toolkit 13.1.

Toolkit 13: Ground surface type		
Available information		**applicable tool**
Detailed geometry of reflective and absorptive surfaces	yes / no	no further action
Land use classification	yes / no	Tool 13.1
Classification of urban/suburban and rural	yes / no	Tool 13.2
No data available	yes	Tool 13.3

Table 5.1- Ground surface type toolkit 13 Good Practice Guide [16]

From land usage maps in GIS, the ground surface can be divided into classes. To each class a default ground factor is assigned. Ground factor equal to 1.0 is absorptive. This method has a moderate complexity and moderate costs and lead to accuracy of 1 dB.

Land usage	Ground factor
forest	1.0
agriculture	1.0
park	1.0
heath land	1.0
paving	0.0
urban	0.0
industrial	0.0
water	0.0
residential	0.5

Table 5.2 - Ground factors for land usages toolkit 13.1 Good Practice Guide [16]

5.4 BUILDINGS

The accuracy of this type of data is extremely important for the quality of the results. The main features are height, volume and use categories. In fact the height influences the noise propagation and people living in dwellings are allocated according to the volume and the use category of the building. A buffer zone of 1.5 k from the road section axis has been considered. Here are reported the used classes:

- **DBTR 2008 - EDI_GPG - Building**. It is a partition of the built structure obtained on the basis of the different building typologies, introducing or architectural partitions or cadastral partitions.
- **DBTR 2008 - UVL_GPG - Volumetric unit.** The surface of each building is divided into volumetric units according to separation lines between elements with homogeneous base but different height. With volumetric unit is intended a significant unit for the quantification of building structure, regardless of the shape and the slope of the roofing. Volumetric unit should be represented when the difference between the roofing elevations are higher than the elevation tolerance chosen, excluding dormers, skylights, balconies in the pitched roof, chimneys, exhaust pipes and every other element that is not directly connected with the volume of the building. Technical volumes like elevators shafts, stairs shafts etc. should be excluded unless they form a distinct building.
- **DBTR 2008 - ACI_GPG - Area for the circulation of bicycles.**

- **DBTR 2008 - ACP_GPG - Area for the circulation of pedestrians.** It includes all the portions of the road that are dedicated to pedestrian, that is to say sidewalks, porches, underground pedestrian passageways, walkways in public green areas etc.
- **DBTR 2008 - AST_GPG - Area of the road**. It represents the overall area covered by the road infrastructure, including the areas for the circulation of vehicles (roadway shoulder, enlargements, traffic islands etc.), areas for the circulation of pedestrians and bicycles and structures for the traffic regulation (traffic dividers, etc.).
- **DBTR 2008 - ITS_STR_GPG - Areas designated for road services**. They are generally constituted by huge areas of pertinance of a transportation infrastructure and they include various objects, structures and zones.
- **DBTR 2008 - ITS_FER_GPG - Areas designated for railway services**. They includes areas for the stop and maneuver, recovery and storage of vehicles.
- **DBTR 2008 - ITS_AER_GPG - Areas designated for airport services**. They include areas for take-off and landing of aircrafts, the airport buildings, green areas, the linking network to goods and passenger yards, storage areas etc.
- **DBTR 2008 - ITS_POR_GPG - Areas designated for port services.** They include areas for the storage and exchange of goods, linking networks on land and off shore.
- **DBTR 2008 - MED_GPG - Monumental facility and urban fabric.** This class includes closed buildings, usually temporary, like shacks, booths and architectural components.
- **DBTR 2008 - MIN_GPG - Industrial facility.** It includes facilities for the production activities like cabins and cockpits, containers, shells etc.
- **DBTR 2008 - MIS_GPG - Sports facility.** It includes sport plants and areas equipped for different sport activities.
- **DBTR 2008 - PSR_GPG - Green area.** It includes green areas for decorative purposes or recreational areas.
- **DBTR 2008 - SCD_GPG - Excavation area or dump.** It is the surface of an excavation area or a landfill.
- **DBTR 2008 - SID_GPG - Area of industrial plant.** Area dedicated to the installation of industrial plants.
- **DBTR 2008 - SUB_GPG - Recreational or service area.** It is part of a recreational or sport facility.

5.4.1 PROCEDURE

The class UVL_GPG continuing information about the building height has been taken as a basis. Further information has been added:

- EDI_GPG has been used to obtain the use classification of the volumetric unit.
- MED_GPG, MIN_GPG and MIS_GPG that have been partially used. For these classes, in fact, only types of structure with significant default height have been selected. The elements of classes MIN_GPG and MIS_GPG have been imported in the model but not included for the noise calculation on the façades. In particular:

Class	Description	Default height [m]
MED_GPG	1 Shack	2.5
MED_GPG	7 Grave	3
MED_GPG	11 Tower	8
MIS_GPG	2 Stairs of sports field	8
MIN_GPG	1 Cabin of electricity	3
MIN_GPG	2 Cemetery	3
MIN_GPG	403 Silo	8

Table 5.3- Summary of the imported elements

- The other classes have been used to double check the use categories.

5.5 DEMOGRAPHIC DATA

The cartographic covering is ***R08_Dati_CPA_2011.*** These data are obtained from the ISTAT, (Italy's National Statistics Institute) referring to Emilia Romagna Region (R08) for the year 2011 [26]. It includes definitive data for municipalities and localities with more than 200 inhabitants, sub-municipal areas and census areas. Data for census sections and localities with less than 200 inhabitants, instead, are temporary and related to the eventual presence of a residual error smaller than 4%. Errors concern the not perfect alignment of building numbers and adjoining sections border lines. These errors will be correct by ISTAT in the next data release.

5.6 ADMINISTRATIVE DATA

- **DBTR 2008 - COM_GPG - Municipality.** It defines the area of the Municipality.
- **DBTR 2008 - LAB_GPG - Inhabited area**. It is formed by areas of residential area, housing unit, productive localities, fraction of sparse buildings, and administrative center of Municipality, Province and Region.
- **DBTR 2008 - LAM_GLI - Administrative limit.** It correspond to the border line of a Municipality, a Province, a Region, or a State.
- **DBTR 2008 - PRV_GPG - Province.** It defines the area of the Province as composition of its Municipalities.
- **DBTR 2008 - REG_GPG - Region.** It defines the area of the Region as composition of its Provinces.

5.7 METEOROLOGICAL DATA COLLECTION

Local weather influences noise propagation and especially for distances of hundreds of meters from the noise source meteorological condition can vary noise levels of some decibels with respect to values obtained in neutral propagation conditions. Wind and air temperature stratification have the major influence on noise propagation, they act independently one from the other. Wind influences propagation depending on the relative position between source and receiver, while vertical air temperature gradient determines isotropic effect on the horizontal plane. These conditions can vary significantly during different seasons. Sufficiently stable results can be obtained through a long period evaluation.

Meteorological data should refer to an average year. A meteorological year is a continuous period of 12 months from the beginning of January to the end of December, and it comprises all 4 seasons. Periods when weather conditions are considered particularly extreme for the area considered should be left out. The meteorological year should be determined averaging several years, the Good Practice Guide [16] recommends 10-years average. Where it is possible data should be acquired from measurements near to the major noise sources of the studied area, if it is not possible, measures from a nearby site that is meteorologically representative can be accounted. Obtaining local meteorological data is the most accurate solution but it is also the most complex and expensive one.

The determination of noise levels requires the study of two specific meteorological conditions: homogeneous conditions and conditions favorable to sound propagation.

The Good Practice Guide [16] in toolkit 17 suggests different methods to assign sound propagation conditions, the level of complexity decreases but also the accuracy does it. Possibilities are: using national regulations or standards otherwise using national default values. These do not exist in Italy. It has been chosen the last possibility that is to use default values given in the toolkit 17. Default values are reported in the table below.

Time period	**Average probability of occurrence during the year of favorable propagation conditions**
Day	50%
Evening	75%
Night	100%

Table 5.4 - Occurrence of favorable propagation conditions toolkit 17 Good Practice Guide [16]

6 NOISE SOURCES DATA COLLECTION

6.1 SPATIAL CHARACTERIZATION OF THE NOISE SOURCE

The European Commission requires that each infrastructure is divided into sections, that can be identified according to the traffic flow variations on junctions. Each section is then divided according to geometrical characteristics as roadway width, slope, etc. and traffic characteristics as traffic pattern, velocity, etc. The division is performed automatically by the software when the different characteristics are inserted.

The spatial characterization should include road typology, geometry, types of pavements. These types of information have been obtained by the classes listed below.

- **DBTR 2008 - TPS_GLI - Municipal road toponym**. The road toponym has a double function: on one side it indentifies areas dedicated to the vehicles circulation, areas for the pedestrian circulation and equipped public areas of the Municipality; on the other side it corresponds to the mobility network assigning for each road element a specific name. Building numbers refer to the name. Toponyms are assigned independently of the road owners. The read network should be completed by those pedestrian routes that have their own road toponym and assigned building numbers or those that serve internal passages. A unique road element can constitute more than one road toponym if it is on the border between two Municipalities. Inversely many road elements can constitute a unique road toponym. This is the case of a road path with the same name which crosses different Municipalities and have different building numbers assignments. The resultant road toponym will show the name of the road and the name of the places crossed.
- **DBTR 2008 - STR_GLI - Road**. It corresponds to the portion of the road network identified as a unique object by the street owner. This class serves the Cadastre of roads according to the regulation of the *Nuovo Codice della Strada*, (New rules of the roads) of the Transportation Department.
- ***PERCORSI STRADALI,* Road paths**. It is the administrative road covering obtained by the Informative Territorial System of the Province of Bologna [28]. It contains identification codes, mileage and exact covering of the studied road sections.
- ***ARCHI STRADALI,* Road sections**. Is the planimetry of the road sections, obtained by the Informative Territorial System of the Province of Bologna [28].
- ***PONTI,* Bridges.** It is the identification of bridges, obtained by the Informative Territorial System of the Province of Bologna [28].

- ***CARREGGIATA,* Roadway.** It contains information on roadway widths and the number of lanes, obtained by the Informative Territorial System of the Province of Bologna [28].

6.1.1 PROCEDURE

The class STR_GLI - Road has been used, since it presents the best alignment with the class UVL_GPG - Volumetric units, representing the receiver buildings. The covering has been corrected and updated, for example roundabouts have been taken into account, according to the other classes listed previously. A further control has been performed checking the present situation on the internet by satellite images and images on the ground level, and if necessary corrections have been made.

6.2 NOISE SOURCE EMISSION DATA

For each road section, the traffic composition, that is to say the percentage of heavy vehicles, the mean velocities of heavy and light vehicles and the type of traffic flow are required.

Different sources for traffic data were available:

MTS is the computerized system for traffic flows monitoring of the Emilia Romagna Region [29]. This system has been realized and co-funded by the Region, the Provinces and ANAS SpA, national roads department. It has the scope of continuous monitoring (24/7) of traffic flows on the major road sections. It is constituted by 278 posts installed on the edge of the roadway and they have a photovoltaic panel as power source. From this source the following data type were available:

a) number of vehicular passages, divided by types of vehicles, and mean velocities. Data are aggregate for periods of 15 minutes. Data cover year 2012 from January to December. For some posts, when data of 2012 were not completely available or reliable they have been integrated with those of 2013;
b) number of vehicular passages, without division according to vehicle size. Velocities are indicated, divided by intervals of 10 km/h. Data cover year 2012 from January to December. For some posts, when data of 2012 were not completely available or reliable they have been integrated with those of 2013;
c) number of vehicular passages, divided by types of vehicles with relative velocities. This represent the most complete type of information. In fact, not only it indicates traffic flow for heavy and light vehicles, but also the respective velocities. Data cover a period of 4 weeks of Spring and Autumn 2012, from May 7th to 20th and from October 8th to 21st;

FREEWAY was a project implementing the Traffic Plan of the Province of Bologna [30]. This type traffic management was based on a multi-disciplinary integrated system for the monitoring and the real-time intervention. The goal was to collect data into a unique model in order to improve mobility, environment protection, air pollution reduction and road safety. Although the fact that the system in no more operative, information has been collected to implement data. 12 FREEWAY posts felt into the studied area and information provided has been accounted. In particular:

d) traffic flow reporting mean velocities for each type of vehicles, aggregated in periods of 1 hour. Data refer to a period of 6 weeks from January to March 2008.

INFOVELOX are speed dissuading devices. They that show the driver the velocity of the vehicle and the speed limit. Fee are not applied in case of speed excess, so driver in many cases do not change their traffic behavior in proximity of these devices. For that reason the data furnished are useful to control applied speed limit and to compare them with the actual driver behavior. Information available regards:

e) traffic flow with velocities, aggregated for periods of 1 hour. Data are referred to August 2007 and May and June 2008.

PROVINCE OF BOLOGNA To integrate the lack of information for some particular road sections other types of data have been provided by the Province of Bologna .

f) annual total vehicular transits estimation, from the *Settore Pianificazione Territoriale e Trasporti della Provincia di Bologna*, territorial and transportation planning department of the Province of Bologna;
g) number of transits aggregated in periods of 1 hour, from direct measurements on the road S.P. 19 San Carlo, obtained by a feasibility study. Reference period is from March 30th 2012 to March 31st 2012;
h) number of transits, divided by vehicle types aggregated in periods of 1 hour, from direct measurements on the road S.P. 4 Galliera in the section between 0+000 and 2+130 mileage, already used for the first cycle of noise mapping. Reference period is October 17th 2003;
i) speed limits in cartographic covering obtained by the Informative Territorial System of the Province of Bologna [28].

6.2.1 PROCEDURE TO DETERMINE THE NUMBER OF TRANSITS.

Since many different typologies of data were available, confrontation and elaborations were necessary.

The number of vehicular transits per hour ,divided for heavy and light vehicle categories, for day, evening and night time periods have been determined mainly referring to (c) data of MTS as they are the most recent and complete. However, due to the limited period of reference, the coherence with the data (a) has been checked.

Comparisons have been made between the daily number of transits obtained by the InfoVelox source (e) and data referring to the same period of 2008 of MTS source obtained on the internet, where the positions of the recording points were similar. Results showed a high discrepancy, for this reasons type (e) have been considered unreliable and discarded.

Comparisons have been done also with the overall annual traffic flow of each road section (f), that has been allocated into the three time periods according to the mean distribution obtained by (a). The daily number of transits in fact, cannot be divided into three parts without a correct distribution, otherwise the number of transits during day period would be highly underestimated and the number of transits during evening and night period would be highly overestimated. The mean distribution obtained by (a) is shown in the table below.

% day period transits	% evening period transits	% night period transits
84.33	6.94	8.73

Table 6.1 - Mean distribution of daily transits according to data source (a)

When data available did not indicate the division between heavy and light vehicles, this is the case of (f) and (g), a procedure analogous to the previous has been applied in order to obtain from (a) the percentage of heavy vehicles for each time period. This is shown in the table below.

% heavy vehicles day period	% heavy vehicles evening period	% heavy vehicles night period
6.83	2.67	7.82

Table 6.2 - Mean percentages of heavy vehicles for day, evening and night period according to data source (a)

Traffic flow has been assigned to each road section. Particular attention has been paid to control if, from the point of recording of traffic data, the presence of junctions could modify the total amount of vehicles. Traffic flow on roundabout and accesses to roundabout has been halved to account for the unique driving direction.

6.2.2 PROCEDURE TO DETERMINE MEAN VELOCITIES.

From data type (2) the mean velocities of heavy and light vehicles categories have been obtained, for day, evening and night period.

From data sources (a) and (b) mean velocities for each daily period have been obtained. These are not divided for vehicles categories so they could not be used directly to characterize the road noise emission, but they have been used to make comparisons for each MTS post. The comparisons had shown the reliability of data type (c).

Thus, data have been used to obtain the mean velocity reductions for heavy vehicles relating to each time period. This have been used for those data types that have no differentiation between vehicles categories (d) and (e).

Speed limit obtained by the Province have been checked and, if needed, updated with those actually present on the road sections (controlling through ground-level images available on the internet).

Velocities obtained by (c), have been grouped accordingly to the speed limits present on the considered sections and three mean velocity profiles have been obtained. These have been applied for those sections where no other information regarding speed was available. They are listed in the tables below.

Speed limit 50/60 [km/]	**Day period mean speed [km/h]**	**Evening period mean speed [km/h]**	**Night period mean speed [km/h]**
Light vehicles	57.9	58.6	60.1
Heavy vehicles	55.7	55.5	59.8

Table 6.3- Mean velocities for day, evening and night period related to speed limits of 50 and 60 km/h

Speed limit 70 [km/]	Day period mean speed [km/h]	Evening period mean speed [km/h]	Night period mean speed [km/h]
Light vehicles	66.4	69.2	71.9
Heavy vehicles	62.6	64.2	67.3

Table 6.4 - Mean velocities for day, evening and night period related to speed limits of 70 km/h

Speed limit 90 [km/]	Day period mean speed [km/h]	Evening period mean speed [km/h]	Night period mean speed [km/h]
Light vehicles	74.2	76.6	80.5
Heavy vehicles	67.7	68.5	73.3

Table 6.5 - Mean velocities for day, evening and night period related to speed limits of 90 km/h

Average speeds of 30 km/h and 50km/h have been assigned respectively to roundabouts and accesses.

7 CALCULATION METHOD

At present Italy does not have national calculation methods, therefore ad interim methods suggested by the END [1] are used. The D.Lgs. 194/05 [10] in attachment 2 indicates as the method to be used for the calculation of the road traffic noise, the official French Method NMPB-Routes-96 (SETRA-CERTU-LCPC-CSTB), mentioned in «Arrêté du 9 mai 1995, relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1996, article 6» [31] and in the French standard «XP S 31-133». For the emission input data the documents refer to the «Guide du Bruit de Transports Terrestres du Novembre 1980». The European Community provided some supplementary documents as «Adaptation and revision of the interim noise computation methods for the purpose of strategic noise mapping» [15].

7.1 GENERAL DESCRIPTION OF NMPB-Routes-96

The method can be divided into steps that are briefly described:

7.1.1 ELEMENTARY SOURCES

The first step is the division of the emitting road into elementary sources positioned in the middle line. Each road must be first modelled using one or more lines if for example each lane is considered separately. Each line is divided into sections of uniform noise emission according to:

- mean traffic speed;
- traffic flow volume;
- traffic flow type;
- road slope;
- ration between light and heavy vehicles;
- road surface type;
- obstacles to sound propagation (e.g. embankments).

Each sources is then divided into a series of elementary point sources that are placed at 0.5 m above the road surface, for all types of traffic.

7.1.2 NOISE EMISSIONS

The following step is determining the sound emission level for each elementary source per octave band and A-wheighted. Noise emission model is described in «Guide du Bruit de Transports Terrestres du Novembre 1980». It takes into account:

- traffic density for each vehicle category;
- traffic characteristics;
- gradient of the section.

a) The sound emission level for a single vehicle E is caused by the movement at speed v of a light vehicle or a heavy vehicle per hour in the case of one of the four flow types and one of the three longitudinal profile types and it is represented by the following formula:

$$E = (L_w - 10\log v\ - 50) \text{ in dB(A)}$$

where:

L_w is the A-weighted vehicle sound power;

v is the mean vehile speed in km/h.

In the table below traffic characteristics influencing noise emission are summarized.

Emission	E	Determined according to nomogram 4.2 from "Guide du bruit" or with the proposed formula below (formula 1). This shows the emission rated per vehicle.	
Vehicles category	lv	Light vehicles	Loaded weight < 3,5T
	hv	Heavy vehicles	Loaded weight ≥ 3,5T
Average speed		lv : [20-130 km/h]	Determined by measurements (V_{50}) or estimated from speed limits and driver behaviour. The last proposal is maybe the easiest and most convenient one.
		hv: [20-100 km/h]	
Road slope		Down	Road gradient > 2% downward
		Up	Road gradient > 2% upward
		Flat	Road gradient ≤ 2%
Type of Traffic		Fluid continuous	- Motorway - Interurban road - Urban expressway (off)rush hours) - Major roads in urban environment - …
		Pulsed continuous	- Urban city-centre roads - Major roads close to saturation - Dispatching or connecting roads with numerous crossings, car parks, pedestrian crossings, junctions to dwellings - …
		Pulsed accelerated	- Expressway after a crossing - Motorway entrance - Tollbooth - …
		Pulsed decelerated	- Expressway before a crossing - Motorway exit - Approach of tollbooth - …

Table 7.1 - Noise emissions AR-INTERIM-CM- Guidance on the application [15]

The following formula have been deduced for the calculation chart number 4.2:

$E = E_0 + a\, log\left(\frac{v}{v_0}\right)$ in dB(A)

where:

v_0= 20 km/h

E_0 and a vary according to traffic condition and are listed in tables.

b) The sound power level per meter of lane for each elementary period k $L_{Aw/m,k}$ is shown in the table below:

Sound power level per meter of lane for each elementary period k		$L_{Aw/m,k} = E_{lv,k} + 10\lg(Q_{lv,k}) + E_{hv,k} + 10\lg(Q_{hv,k})$
Traffic Load	Q	Number of vehicles (lv and hv) during the period under consideration (reference period or elementary period in case of varying traffic characteristics)

Table 7.2- Sound power level AR-INTERIM-CM- Guidance on the application [15]

where:

$E_{lv,k}$ is the equivalent sound level at the reference isophone due to a single light vehicle,

$E_{hv,k}$ is the equivalent sound level at the reference isophone due to a single heavy vehicle,

$Q_{lv,k}$ is traffic load in terms of light vehicles for the duration of the reference time interval

$Q_{hv,k}$ is traffic load in terms of heavy vehicles for the duration of the reference time interval

c) The average **sound power level per meter of lane, corrected in the light of the road surface $L_{Aw/m,\Psi}$** is shown in the table below:

<table>
<tr><td colspan="2">Average sound power level per meter of lane, corrected in the light of the road surface – Variable traffic conditions during the reference period (k > 1)</td><td colspan="4">$L_{Aw/m,\Psi} = 10\lg\sum_k 10^{\frac{(L_{Aw/m,k}+\Psi)}{10}} \cdot \frac{h_k}{h_p}$</td></tr>
<tr><td colspan="2">Sound power level per meter of lane, corrected in the light of the road surface – Same traffic conditions during the reference period</td><td colspan="4">$L_{Aw/m,\Psi} = L_{Aw/m} + \Psi$</td></tr>
<tr><td rowspan="6">Correction for road surfacing</td><td rowspan="6">Ψ</td><td>Road Surface Categories</td><td colspan="3">Noise Level Correction</td></tr>
<tr><td rowspan="2">Porous Surface</td><td>0-60 km/h</td><td>61-80 km/h</td><td>81-130 km/h</td></tr>
<tr><td>-1 dB</td><td>-2 dB</td><td>-3 dB</td></tr>
<tr><td>Smooth asphalt (concrete or mastic)</td><td colspan="3">0 dB</td></tr>
<tr><td>Cement Concrete and Corrugated asphalt</td><td colspan="3">+2 dB</td></tr>
<tr><td>Paving Stones</td><td colspan="3">+3 dB</td></tr>
<tr><td>Length of the elementary period</td><td>h_k</td><td colspan="4">Length of the elementary period under consideration, expressed in hours</td></tr>
<tr><td>Length of the reference period</td><td>h_p</td><td colspan="4">Length of the reference period under consideration (day, evening or night), expressed in hours</td></tr>
</table>

Table 7.3- Sound power level AR-INTERIM-CM- Guidance on the application [15]

c) The **sound power level of an elementary source i in a given octave band j L_{Awi}** is shown in the table below:

<table>
<tr><td>Sound power level of an elementary source i in a given octave band j</td><td colspan="8">$L_{Awi} = L_{Aw/m,\Psi} + 20 + 10\lg(l_i) + R(j)$</td></tr>
<tr><td>Length of elementary source line Li</td><td colspan="8">Length of the elementary source line resulting from the segmentation used for the calculation</td></tr>
<tr><td rowspan="3">Spectral value for octave band j R(j)</td><td>j</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td rowspan="3">Normalised A-weighted octave band traffic noise spectrum calculated from third octave spectrum of ISO 1793-3</td></tr>
<tr><td>Octave band (Hz)</td><td>125</td><td>250</td><td>500</td><td>1000</td><td>2000</td><td>4000</td></tr>
<tr><td>Value of R(j) in dB(A)</td><td>-14.5</td><td>-10.2</td><td>-7.2</td><td>-3.9</td><td>-6.4</td><td>-11.4</td></tr>
</table>

Table 7.4- Sound power level AR-INTERIM-CM- Guidance on the application [15]

7.1.3 METEOROLOGICAL CONDITIONS

The third step is to investigate all the paths of **noise** propagation between each source and the receiver (direct, reflected and diffracted paths). There are two distinct types of sound propagation due to meteorological condition:

- meteorological condition favourable to sound propagation;
- netral meteorological conditions.

Favourable conditions are commonly moderate or strong wind in the direction of sound propagation and nocturnal clear sky with weak wind.

Neutral condition result in straight sound rays unaffected by wind.

The two meteo conditions result in different calculations for the paraeters that influences the sound propagations:

Sound level with favourable conditions:

$L_F = L_w - A_{div} - A_{atm} - A_{grd,F} - A_{dif,F}$ in dB

Sound level with homogeneous conditions:

$L_H = L_w - A_{div} - A_{atm} - A_{grd,H} - A_{dif,H}$ in dB

Sound level at the receiver is calculated for both meteo conditions, which are then combined according to the ratio of each of the two conditions, for the day, evening and night periods over the year and it is:

$L_{longterm} = 10\log(p \cdot 10^{L_F} + (1-p) \cdot 10^{L_H})$ in dB

Local meteo data should be preferred otherwise default values are give in Good Practice Guide [16] Toolkit 17 and reported in chapter 5.

Time period	Average probability of occurrence during the year of favorable propagation conditions
Day	p=0.5
Evening	P=0.75
Night	P=1.0

Table 7.5- Average probability of favorable condition toolkit 17 Good Practice Guide [16]

7.1.4 NOISE PROPAGATION PARAMETERS

The following **parameters** are determined on each of the paths of propagation, on the basis of favourable and uniform conditions:

- The attenuation of the noise level owing to the noise transmission mode, called the **geometrical divergence**. This affects the overall dB(A) level.
- **Atmospheric absorption**, in accordance with the distance between source and receiver and a variable coefficient in accordance with the octave band under consideration.
- The **ground absorption** per octave band for favourable and uniform meteorological conditions.
- The **diffraction factor** for favourable and uniform meteorological conditions, so as to consider the proportion of noise diffracted by various obstacles.
- A factor taking account of **reflections** and influencing the overall level.

7.1.4.1 GEOMETRICAL DIVERGENCE A_{div}

The sound attenuation due to geometrical divergence A_{div} (decreasing of sound level due to propagation distance) is calculated in the general way (based on spherical propagation):

$A_{div} = 20\log(d) + 11$ in dB

where d is the distance between source and receiver.

7.1.4.2 ATMOSPHERIC ABSORPTION A_{atm}

The sound attenuation due to atmospheric absorption A_{atm} is calculated in the general way:

$A_{atm} = \frac{\alpha_i d}{1000}$ in dB where

d is the distance between source and receiver.

α_i is the air attenuation coefficient at the nominal midband frequency for each octave band. A table of the air attenuation coefficients according to ISO 9613-1 [21] has to be given for several sets of temperature and relative humidity. The relevant data have to be chosen from this table on a national basis.

7.1.4.3 GROUND ABSORPTION A_{grd}

The sound attenuation due to the ground effect A_{grd}, caused by the interference between the sound reflected on the ground and the sound propagating directly from the source to the receiver, is taken into account in two different ways, depending on the type of sound propagation which is caused by the meteorological conditions.

The attenuation for favourable conditions $A_{grd,F}$. is calculated according to the method given in ISO 9613-2 [22], which is used in several European countries.

The attenuation for homogeneous conditions $A_{grd,H}$. is calculated according to a formula taking into account the ground coefficient G. If G = 0 (reflecting ground) $A_{grd,H}$ = - 3 dB.

7.1.4.4 DIFFRACTION A_{dif}.

Diffraction might be due to thin and thick barriers, buildings, natural or artificial mounds as well as edges of an embankment, cutting or viaduct. In case a diffraction is effective, the ground attenuation A_{grd} has not to be taken into account.

The calculation of the sound attenuation by diffraction A_{dif} is described in detail for the 2 types of sound propagation. Favourable conditions assume curved ray paths, while homogeneous conditions assume straight ray paths. Several sketches show how to calculate the path difference in both cases. If path difference is below 0.034 m diffraction effect is ignored. From the path difference the attenuation due to diffraction is calculated by a series of formulae.

7.1.4.5 REFLECTION

The reflections on vertical obstacles are treated using image-sources. An obstacle is taken as vertical when its incline regarding to a vertical direction is less than15 degrees. If the reflections on strongly inclined obstacles are needed then the pre-sent method has to be applied in 3D.

Obstacles whose dimensions are small regarding to the wave-length have to be neglected in the calculation of reflection. The sound power level of the image source has to take into account the absorption coefficient of the reflecting surface.

7.2 ADAPTATION TO THE USE IN NOISE MAPPING ACCORDING TO END

7.2.1 NOISE INDICATORS

Noise indicators used should be those required by the Directive 2002/49/EC [1], that is to say day, evening, night time period indicators and L_{den}.

7.2.2 IMMISSION POINTS

In END the height of the immission point is prescribed with 4 m. In NMPB there is only said, that the height of the receiver point above the ground has to be at least 2 m. So for calculations according to END the height of the immission point may be chosen with 4m.

7.3 MODEL'S LIMITATIONS

The following limitations apply to the model:

- The reception point has to be at least 2 metres off the ground.
- The results achieved by using the model are significant up to 800 metres from the road under consideration.
- The minimum vehicle speed is 20 km/h.
- The emission model is old and may not represent emissions form modern cars.

7.4 SOFTWARE USED: SoundPLAN

Software guidelins are available in the AR-INTERIM-CM [15]. In the guidelines the minimum requirements that the software should have are listed. The software used, SoundPLAN, satisfies all the requirements. Some particular features of SoundPLAN are underlined [24].

7.4.1 PHYSICAL DESCRIPTORS OF NOISE

The units for noise measurement are dB(A). The descriptor in brackets (A) indicates the noise level is corrected to suit the human ear which is not linear like a sound level meter but is frequency dependent. Most of the time dB(A) refers to the L_{eq}, the energy equivalent noise level. Along with the calculation of noise levels for 24 hours, different time penalties need to be considered. SoundPLAN processes the hourly L_{eq} and then rates them in accordance to therequired descriptors. SoundPLAN is delivered with several fixed noise assessment standards, additional assessment types can be created in the Geo Database under the noise limit files. The definitions can include multiple time slots and penalty times. The noise assessment standard of choice needs to be selected in the calculation parameters or in the run file.

7.4.2 NOISE SOURCES

Noise can be emitted from various sources, most of which you can calculate with SoundPLAN. Sources include roads, railroads, airports, point, line and area sources inside and outside buildings. All sources have their own definition file for coordinates and other descriptions. For road, railroad and aircraft noise, SoundPLAN contains a source model calculating the sound power or a derived value from the traffic data. Industry noise requires use of measured data. The emission data is written in specialized control lines and defines the next section of geometric data. The source type determines the source geometry entry. A point source needs only one coordinate. A line source is defined with at least 2 points. If more than 2 points are chained together, SoundPLAN assumes there is a continuous poly line. An area source requires at least 3 coordinates. As long as the area is defined as one plain, SoundPLAN can accept any number of coordinates for the area source. If the source is not on one plain, you need to divide it into smaller source polygons with each polygon on a plain. If area sources contain more than 3 coordinates, SoundPLAN separates them into a series of triangles at loading time.

The second limitation for line and area sources is that the condition within the source needs to be uniform. If there is a change in traffic volume or speed, there is also a change in noise emission and thus a new source definition is necessary. Roads, railroads and industry sources are only definitions of noise emission. If the road is on an embankment, the embankment may act as a shield for other sources. In order to recognize this, SoundPLAN needs the definition of the embankment in a separate file defining it either as a reflecting object or marking it with a series of elevation lines. As the program is user friendly, you can copy the coordinates from one type of data into another.

Source type	Sound-PLAN module	Source type	Calculation of the mean emission
road	road	line	emission can be calculated and inserted in control line
parking lots	road	area	emission calculated in control line
railroad	railroad	line	emission is calculated in specialized files and referenced in the source geometry
train depo	industry	point, line, area	definition via measured data in the industry module
industry	industry	point, line, area	emission level administrated in libraries or from inside calculations and transmission
leisure facilities	industry	point, line, area	same as industry calculations
aircraft	aircraft	line	emissions defined for different aircraft classes from a setup file

Table 7.6- SoundPLAN types of noise source [24]

7.4.3 TYPES OF RECEIVERS

There are 3 tyoes of the receiver:

- single point receiver;
- grid of points on building façades;
- grid points for a defined elevation above the terrain.

From each type of receiver chosen a different output representation is obtained.

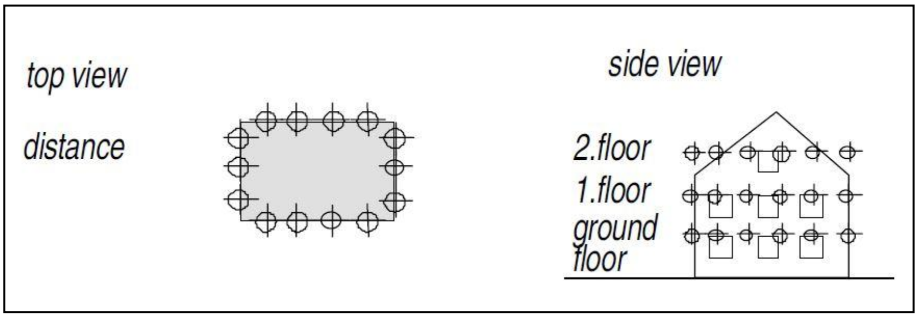

Figure 7.1 - SoundPLAN grid of pioints on building façades [24]

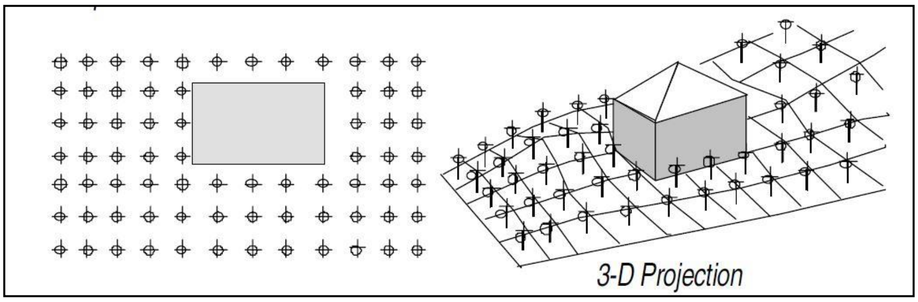

Figure 7.2 SoundPLAN grid of points for a defined elevation above the terrain [24]

7.4.4 CALCULATING PRINCIPLES

As noise maps are created from single point calculations, it is very important to describe the noise level calculation process for single receivers. All sources are independent and can be calculated separately. Results of all source contributions can be added to the imission level using the formula:

$$L_{i,sum} = 10 \cdot \log(\Sigma\left(10^{\frac{L_{ii}}{10}}\right))$$

The single source contribution can be described by:

$L_i = L_w - C_1 - C_2 \ldots C_n$

where:

L_i is the imission level at the receiver;

L_w is the sound power (or equivalent);

$C_1..C_n$ are coefficients describing different propagation aspects.

The sound level at a receiver is derived from the sound power and the propagation. The propagation coefficients are spreading, air absorption, screening, ground effect and reflection.

7.4.5 THE SEARCH ANGLE METHOD

The software searches propagation rays with a sector method. Scanning triangles start from the receiver to find sources, reflections, screens and geometry modifying the ground attenuation. A constant increment of 1 degree is applied as default setting, but the user can choose any increment. Tradeoff between accuracy and speed should be considered, in fact, the finer the increment is, the more accurate and slower the calculations are.

When a source is found, the part of the source contained in the search triangle is autolmatically calculated and processed. Area sources and industrial line sources remain areas and lines for all calculations. Line sources from road and rail are abstracted to point sources and treated like point sources in the calculation. This is shown in the figure below.

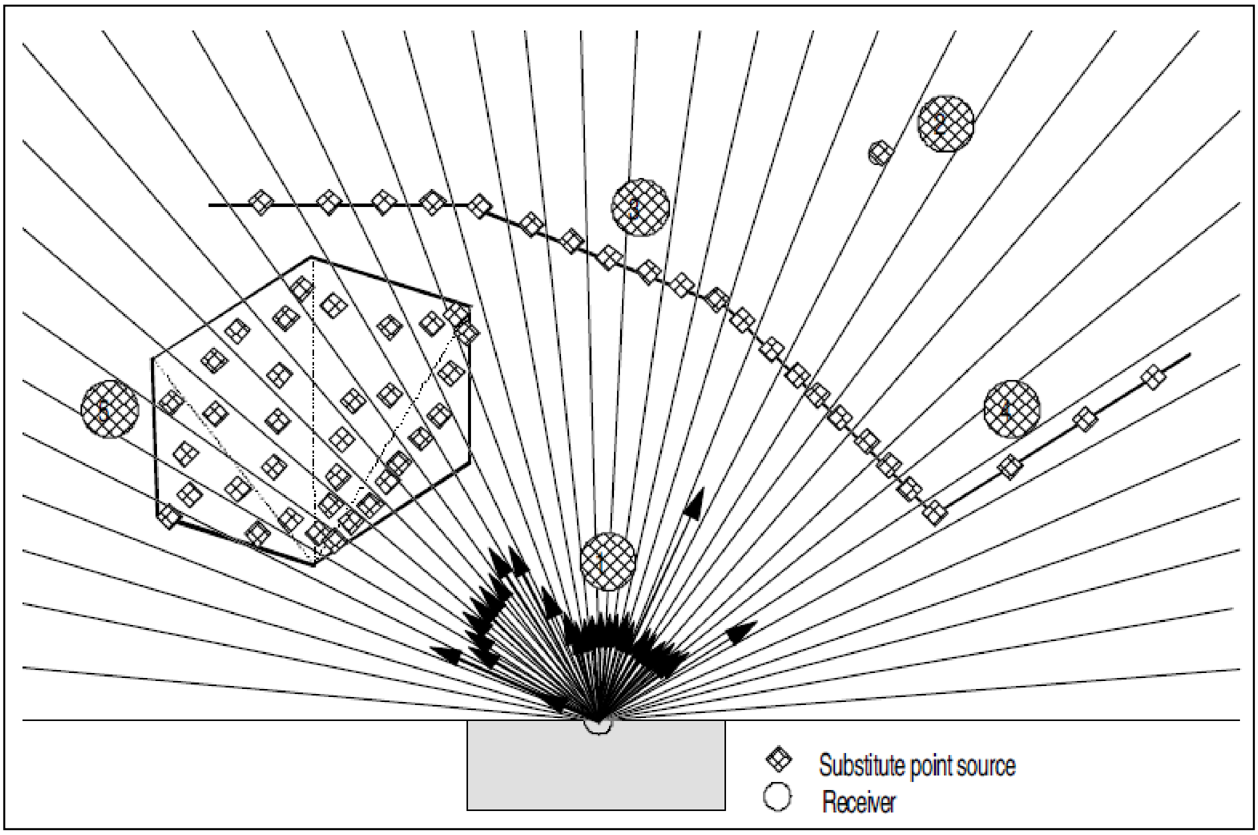

Figure 7.3- The searching triangles method for road line sources abstracted into point sources [24]

From the figure it is possible to understand the following principles:

- the noise contributions hitting the receiver from different directions are drawn to scale with the receiver at the center. From the length of the arrows, the noise contribution to the direction pointed by the ray can be measured;
- point sources are automatically accounted for in the sector where they are found. The calculation is performed accounting for the line connecting the source and the receiver;

- for line sources the line connecting the source and the receiver is in the middle of the triangle;
- line sources are automatically divided into segments fitting inside the search triangles.
- line sources leading away from the receiver are divided so that the condition $L < 0.5 * S$ is fulfilled, where L is the lenght ot the source segment and S is the distance between source and receiver;
- area sources are clipped with the search triangle before performing the noise calculations. The corners of the clipped area sources are further checked for propagation differences. If the corners deviate more than a definable limit, the resulting area source is partitioned further until the differences are negligible.

The calculation inside SoundPLAN is split into a search part and an acoustics calculation part.

In the searching process the sections of sources which are within the search triangles are found and marked. After the direct input of noise is calculated, SoundPLAN calculations mirror the position of the receiver and look for reflected noise.

The model is sectioned and stored in SoundPLAN calculation core. A list of object found is created and organized accordingly to the distance from the receiver.

The final step is the process of the acoustics starting from the receiver and searching for the next source in the list. When a source is found, the noise contribution for the receiver is calculated. These calculations evaluate spreading, air absorption, screening, ground effect, reflection and volume type absorption. The contributions of the sources found in the search triangle are added for the cumulative noise level.

7.4.6 SPEED V/S ACCURACY

Depending on the distance between source and receiver, a short part, maximum half of a search increment, of a source or a gap between buildings may not be recognized correctly.

Decreasing the increment between the search rays will increase the accuracy but will result in a linear increase of calculation time. Obviously it is necessary to take into account a tradeoff between calculation time and accuracy.

In general, it can be assumed that the calculation could be completed more quickly if the program would simultaneously search for sections with the same geometry and calculate the geometry fitting. This is the case for small models where calculation time is not a problem. But this is not true for more complicated model, where the search triangles method is quicker. The search ray method has another advantage in that only a small segment of the geometry needs to be searched at one time, which saves a lot of calculation time.

7.4.7 TYPES OF OUTPUTS

In chapter 4 a list of the different map types required has been provided. From the software it is possible to obtain different types of outputs. All maps are created from noise levels calculated at specific locations. The only difference concerns how the receivers are generated. The specific features of the single receiver are presented in the following picture.

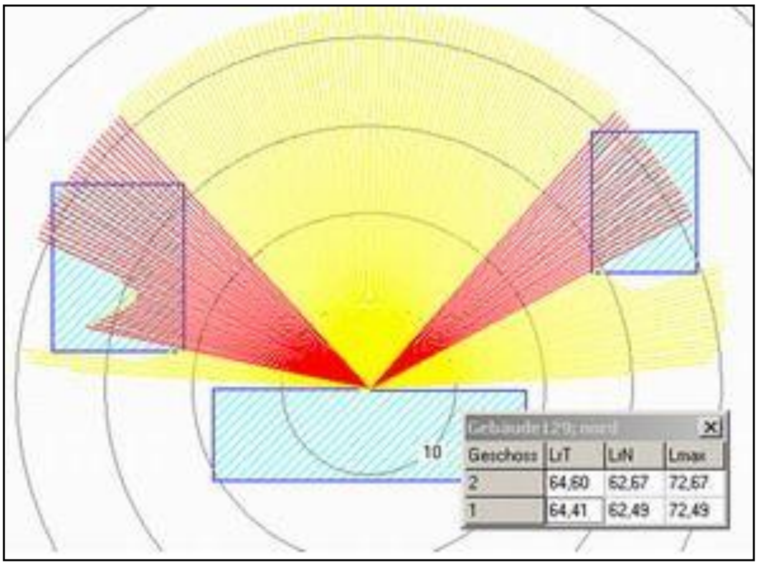

Figure 7.4- Single point receiver at the end of a calculation [24]

The type of outputs that can be obtained are:

- grid noise maps, created defining a regular grid pattern superimposed on the model within the defined studied area.It contains the results from many single points calculations that are the receivers positioned on the nodes of the grid. The elevation of the receiver is calculated first, followed by the boise level calculation for every node. The map is assembled to a user definable scale.
- noise contour maps derived from grid noise maps. Contour lines can be calculated with several options;

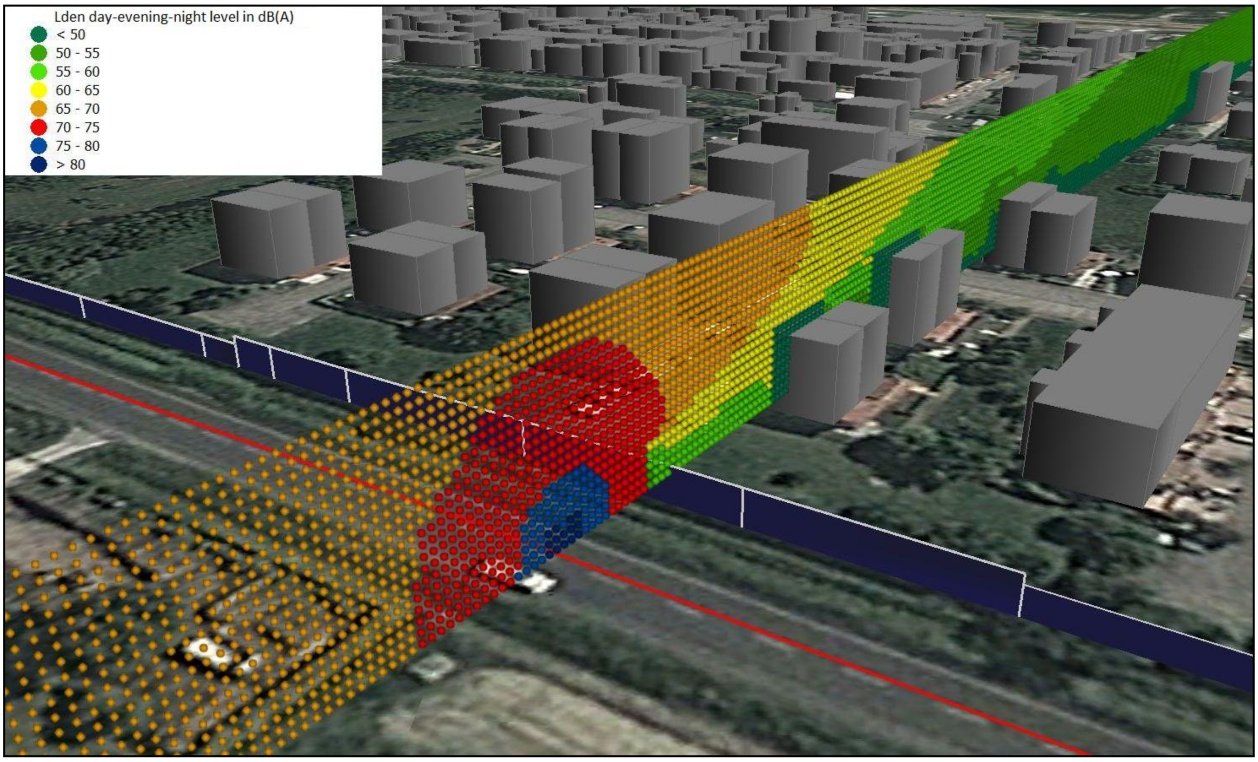

Figure 7.5- Example of noise contour map section

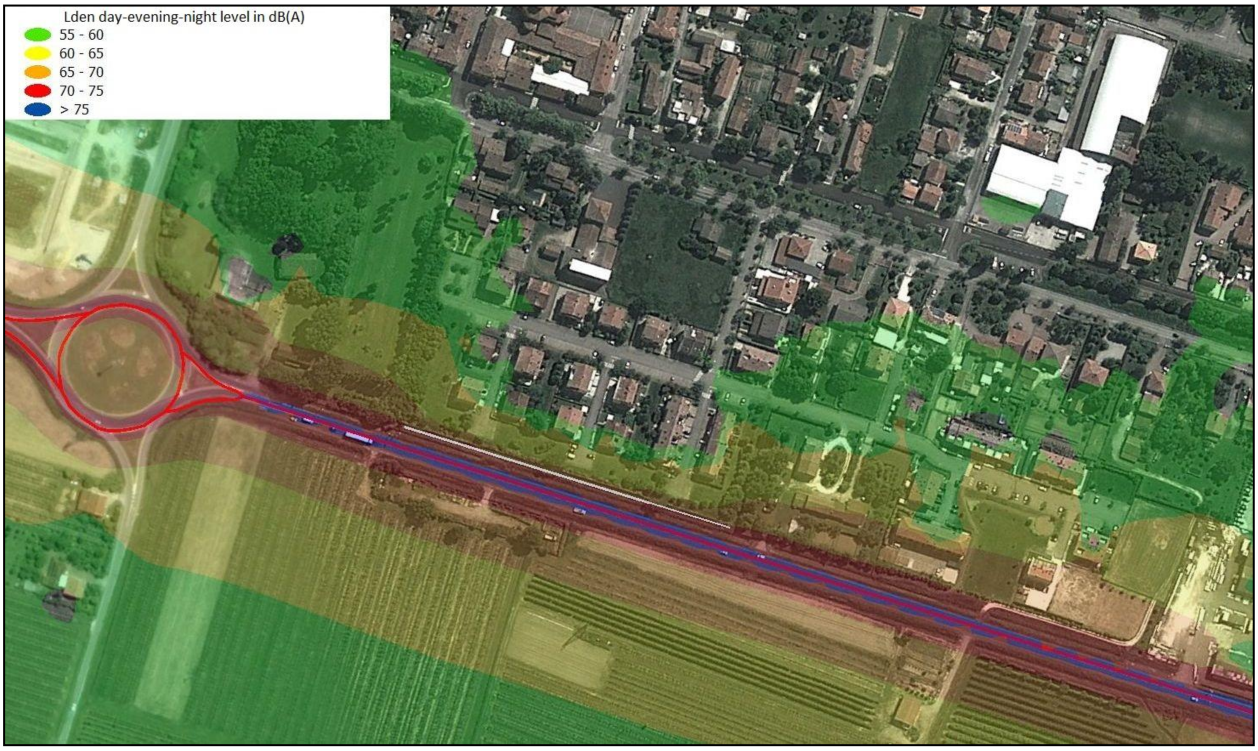

Figure 7.6- Example of noise contour map

Figure 7.7 - Example of noise contour map with 3d objects

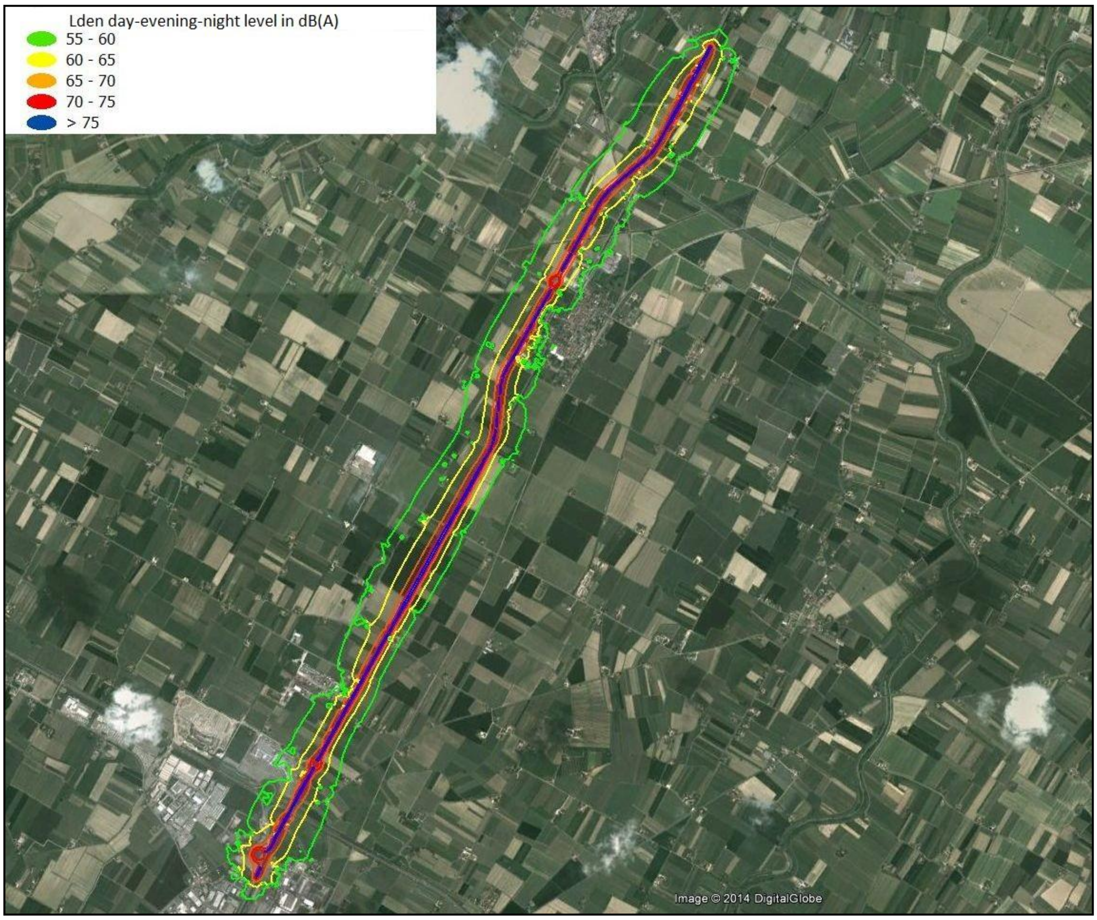

Figure 7.8 - Example of noise contour map

- façade noise maps are made by an assembly of single point receivers of different locations along the façade. An automatic calculation generates receivers and calculate noise levels along façades. Buildings for the calculation are marked and the spacing is defined.

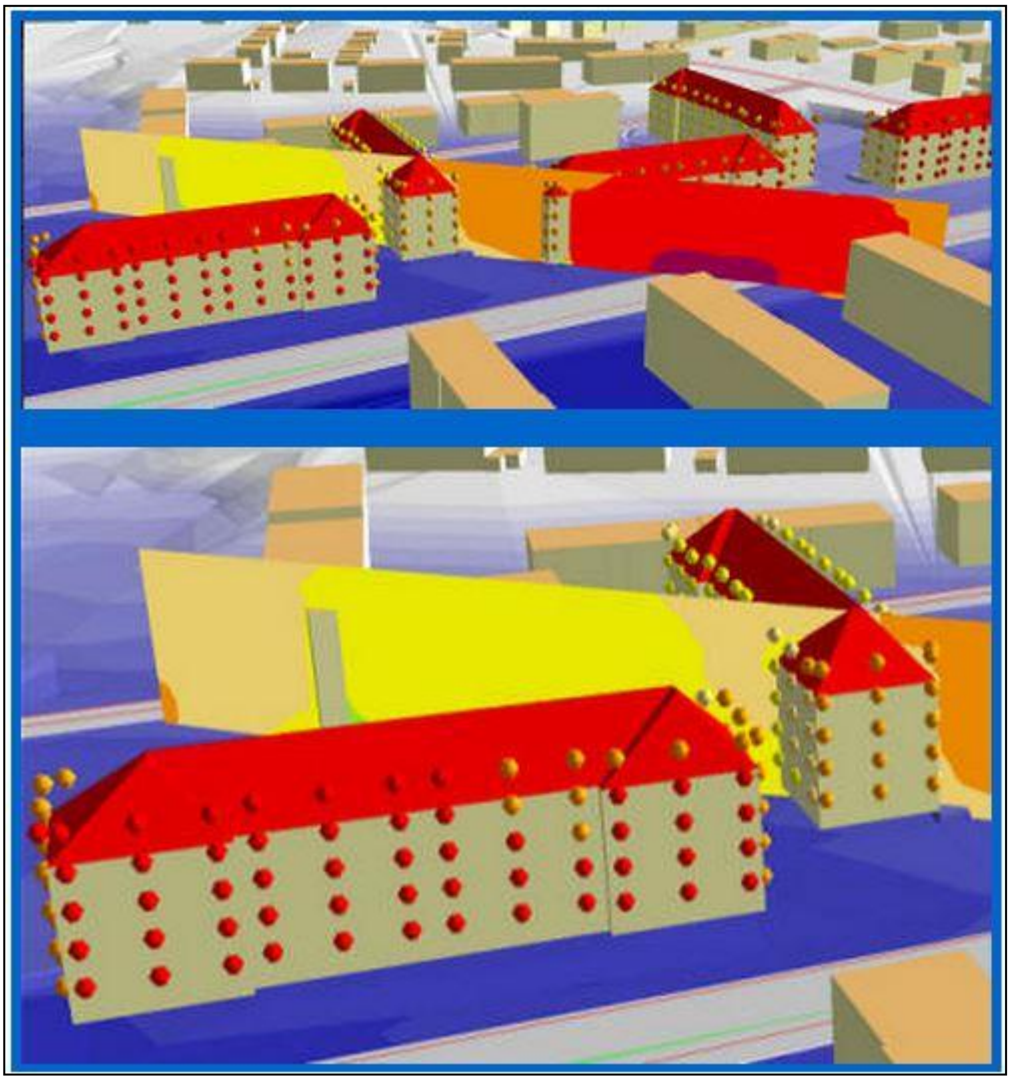

Figure 7.9 - Example of façade noise map

8 MODEL CALIBRATION

The model calibration is paramount to the validity of the model itself. Uncertainties in the results have different causes. Here some of them are listed: [23]

- the uncertainty of input data of the calculation model;
- the uncertainty due to hypothesis like geomorphology assumptions, meteorological assumptions, etc.;
- the finite number of digits of the calculation machine;
- the uncertainty due to the combination of input data according to complex algorithms, also called "calculation noise".

The model calibration is the comparison of the model results with measurements and it is the tool to restrain and reduce uncertainties. Measurements should refer to the studied area and only if this is not possible, they should refer to a case similar to the studied one. Obviously some uncertainties are intrinsic to the measurement process, for example the precision of the equipment and of the procedures.

The methodology for the global calibration of the model of a given area can be simplified into a punctual calibration. Punctual calibration might imply more points or one single point. The discrepancy between calculated values and measured ones is fundamental. Moreover, it is possible to pinpoint some main features of the calibration:

- the number of points of measurement should be representative of the different situations occurring in the studied area, like source types, receiver types, etc.;
- the points of measurement should be univocally identified through georeferentiation, photographs, etc.;
- noise measurements should be coupled with traffic flow measurements according to the different types of sources, or with records of traffic flow obtained by infrastructure managements;
- measurements should be performed in accordance with the law, with phonometric equipment of class 1 and by environmental acoustics technicians;
- measurements should last at least 24 consecutive hours;
- meteorological conditions during measurements should be similar to those assumed in the model.

Unfortunately, for the studied case, there were neither experimental data available nor allocated budget for further measurements. Nevertheless, in order to check in some way the response of the model, a short phonometric survey has been performed.

8.1 PROCEDURE

The survey has been performed between December 19 and December 21 of 2013. Meteorological conditions were stable, no precipitation occurred and wind velocity remained < 5 m/s.

Two points of measurements have been chosen in the proximity of the MTS post n. 156 located along the road SP 253 San Vitale. As it has been seen in Chapter 6, the traffic records of MTS posts have been used to model the noise source. The traffic flow records of MTS post n. 156 have been used to model the noise source for the road section in the proximity of the post, to the extent the source characteristics remain constant, for example the geometry of the road transversal section, the lack of junctions and so on.

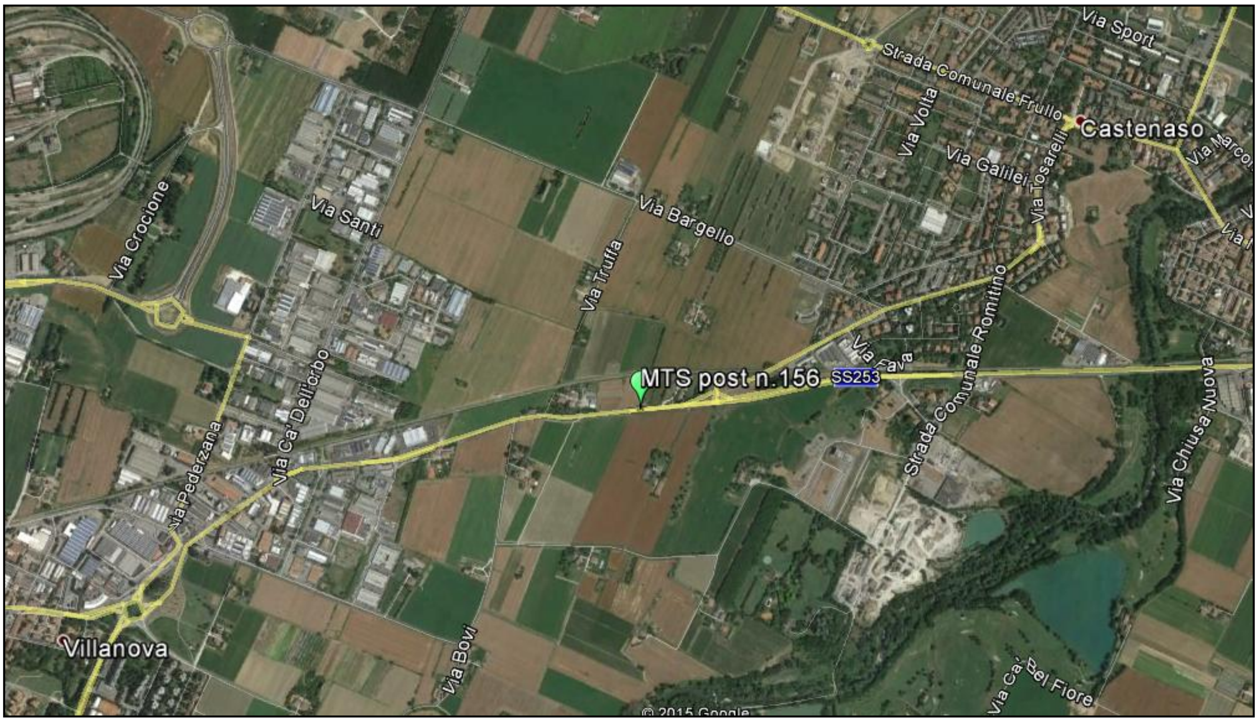

Figure 8.1 - Localization of the MTS post n.156

Figure 8.2 - MTS post n. 156 along provincial road sp. 253 San Vitale

The road section studied is almost rectilinear and junctions are such that they do not greatly influence the traffic flow. So it has been assumed that the velocities and the number of passages and the heavy vehicles percentages for the day evening and night period measured at MTS post were applicable to the whole road section influencing the receiver represented by the points of measurements.

Traffic flow data recorded by MTS post n. 156 are reported in the tables below.

Day	Type of vehicles	Passages Day period	Passages Evening period	Passages Night period
Thursday, December 19th, 2013	Light	1.457,43	814,50	201,63
	Heavy	59,86	1,00	5,25
	% Heavy	3,95%	0,12%	2,54%

Table 8.1 - Traffic flow recorded by the MTS post n. 156 the day 19/12/2013

Day	Type of vehicles	Passages Day period	Passages Evening period	Passages Night period
Friday, December 20th, 2013	Light	1.485,29	900,00	233,63
	Heavy	46,50	1,00	7,25
	% Heavy	3,04%	0,11%	3,01%
Saturday, December 21st, 2013	Light	1.299,07	800,50	277,75
	Heavy	10,43	1,50	2,38
	% Heavy	0,80%	0,19%	0,85%

Table 8.2 Traffic flow recorded by the MTS post n. 156 the day 20 and 21/12/2013

Day	Type of vehicles	Passages Day period	Passages Evening period	Passages Night period
Annual mean values 2012	Light	1.161,35	720,06	201,65
	Heavy	39,12	3,75	5,50
	% Heavy	3,26%	0,52%	2,65%

Table 8.3 Traffic flow recorded by the MTS post n. 156 annual mean values of year 2012

Two phonometers have been placed in the correspondence of the chosen measurement points at a height of 4 meters. The first one is at about 440 meters from the MTS post n. 156 and the second one at about 366 meters. The layout is shown in the picture below.

Figure 8.3 - Measurement points along provincial road sp 253 San Vitale

Characteristics of phonometer at measurement point n.1:

- constructor: 01-dB
- model: duo
- serial number: 10448
- last calibration: 2012/04
- survey period: from Thursday December 19th, 2013 (11:43) to Saturday, December 21st, 2013 (14:22)
- position: next to an advertising billboard
- approximate distance from noise source: 88 meters

Figure 8.4 - Aerial view of the first measurement point

Figure 8.5 - The phonometer at the first measurement point

Characteristics of phonometer at measurement point n.2:

- constructor: 01-dB
- model: duo
- serial number: 10414
- last calibration: 2012/04
- survey period: from Thursday December 19th, 2013 (12:31) to Saturday, December 21st, 2013 (14:22)
- position: next to a dwelling
- approximate distance from noise source: 74 meters

Figure 8.6 - Aerial view of the second measurement point

Figure 8.7 . The phonometer at the second measurement point

8.2 VERIFICATION OF ONE DAY

The following data have been inserted in SoundPLAN:

- Traffic flow: data related to Friday, December 20th
- Velocities: mean velocities obtained by the analysis of single transits referring to typical weeks.

CALCULATED VALUES

RNo	Receiver	Rec ObjID	Fl	Lden in dB(A)	Ld in dB(A)	Le in dB(A)	Ln in dB(A)
1	10448	1135652	GF	61,4	60,4	57,2	52,9
2	10414	1135656	GF	62,5	61,8	58,2	53,7

Table 8.4 - SoundPLAN calculated values for one day simulation.

MEASURED VALUES

Phonometer 1:

File	20131220_000000_000000.cmg	
Ubicazione	Rocco-DUO #10448	
Tipo dati Pesatura Unit	Leq A dB	
Inizio Fine	20/12/13 00.00.00.000 20/12/13 23.59.59.500	
Periodo	Valutazione Giorno-Sera-Notte Lden (Lden)	
Intervallo temporal	Day 06:00 20:00 Kd = 0 dBA Sera 20:00 22:00 Ke = 5 dBA Lun Mar Mer Gio Ven Sab Dom Night 22:00 06:00 Kn = 10 dBA Lun Mar Mer Gio Ven Sab Dom	
	Lden dB	Leq dB
Livello	60,7	57,4
Periodo	Day (Ld)	
Intervallo temporal	Day 06:00 20:00 Kd = 0 dBA	
	Ld dB	Leq dB
Livello	58,9	58,9
Periodo	Evening (Le)	
Intervallo temporal	Evening 20:00 22:00 Ke = 0 dBA	
	Le dB	Leq dB
Livello	57,2	57,2
Periodo	Night (Ln)	
Intervallo temporal	Night 22:00 06:00 Kn = 0 dBA	
	Ln dB	Leq dB
Livello	52,5	52,5

Table 8.5 - Measured values for measurement point 1.

Phonometer 2:

File	20131220_000000_000000.cmg	
Ubicazione	10414-DUO #10414	
Tipo dati Pesatura Unit	Leq A dB	
Inizio Fine	20/12/13 00.00.00.000 21/12/13 00.00.00.000	
Periodo	Valutazione Giorno-Sera-Notte Lden (Lden)	
Intervallo temporal	Day 06:00 20:00 Kd = 0 dBA Sera 20:00 22:00 Ke = 5 dBA Lun Mar Mer Gio Ven Sab Dom Night 22:00 06:00 Kn = 10 dBA Lun Mar Mer Gio Ven Sab Dom	
	Lden dB	Leq dB
Livello	61,9	58,6
Periodo	Day (Ld)	
Intervallo temporal	Day 06:00 20:00 Kd = 0 dBA	
	Ld dB	Leq dB
Livello	59,9	59,9
Periodo	Evening (Le)	
Intervallo temporal	Evening 20:00 22:00 Ke = 0 dBA	
	Le dB	Leq dB
Livello	60,1	60,1
Periodo	Night (Ln)	
Intervallo temporal	Night 22:00 06:00 Kn = 0 dBA	
	Ln dB	Leq dB
Livello	53,4	53,4

Table 8.6 - Measured values for measurement point 2.

8.3 VERIFICATION OF TWO DAYS

The following data have been inserted in SoundPLAN:

- Traffic flow: mean annual data referring to year 2012
- Velocities: mean velocities obtained by the analysis of single transits referring to typical weeks.

CALCULATED VALUES

RNo	Receiver	Rec ObjID	Fl	Lden in dB(A)	Ld in dB(A)	Le in dB(A)	Ln in dB(A)
1	10448	1135652	GF	60,5	59,4	56,4	52,1
2	10414	1135656	GF	61,6	60,8	57,4	52,8

Table 8.7 - SoundPLAN calculated values for two days simulation.

MEASURED VALUES

Phonometer 1:

File	20131219_114323_000000_1.CMG
Ubicazione	Rocco-DUO #10448
Tipo dati Pesatura Unit	Leq A dB
Inizio Fine	19/12/13 11.43.23.000 21/12/13 14.22.12.000
Periodo	Valutazione Giorno-Sera-Notte Lden (Lden)
Intervallo temporal	Day 06:00 20:00 Kd = 0 dBA Sera 20:00 22:00 Ke = 5 dBA Lun Mar Mer Gio Ven Sab Dom Night 22:00 06:00 Kn = 10 dBA Lun Mar Mer Gio Ven Sab Dom

	Lden dB	Leq dB
Livello	60,6	57,4
Periodo	Day (Ld)	
Intervallo temporal	Day 06:00 20:00 Kd = 0 dBA	
	Ld dB	Leq dB
Livello	58,7	58,7
Periodo	Evening (Le)	
Intervallo temporal	Evening 20:00 22:00 Ke = 0 dBA	
	Le dB	Leq dB
Livello	57,4	57,4
Periodo	Night (Ln)	
Intervallo temporal	Night 22:00 06:00 Kn = 0 dBA	
	Ln dB	Leq dB
Livello	52,5	52,5

Table 8.8 - Measured values for measurement point 1

Phonometer 2:

File	20131219_123133_000000_1.CMG
Ubicazione	10414-DUO #10414
Tipo dati Pesatura Unit	Leq A dB
Inizio Fine	19/12/13 12.31.33.000 21/12/13 11.33.12.040
Periodo	Valutazione Giorno-Sera-Notte Lden (Lden)
Intervallo temporal	Day 06:00 20:00 Kd = 0 dBA Sera 20:00 22:00 Ke = 5 dBA Lun Mar Mer Gio Ven Sab Dom Night 22:00 06:00 Kn = 10 dBA Lun Mar Mer Gio Ven Sab Dom

	Lden dB	Leq dB
Livello	62,1	58,8
Periodo	Day (Ld)	
Intervallo temporal	Day 06:00 20:00 Kd = 0 dBA	
	Ld dB	Leq dB
Livello	60,2	60,2
Periodo	Evening (Le)	
Intervallo temporal	Evening 20:00 22:00 Ke = 0 dBA	
	Le dB	Leq dB
Livello	59,6	59,6
Periodo	Night (Ln)	
Intervallo temporal	Night 22:00 06:00 Kn = 0 dBA	
	Ln dB	Leq dB
Livello	53,5	53,5

Table 8.9 - Measured values for measurement point 2.

8.4 RESUMING

POINT 1 one day	Lden in dB(A)	Ld in dB(A)	Le in dB(A)	Ln in dB(A)
CALCULATED	61.4	60.4	57.2	52.9
MEASURED	60.7	58.9	57.2	52.5
difference	**0.7**	1.5	0	**0.4**

Table 8.10 - Comparison between measured and calculated values for one day period, measurement pt 1

POINT 1 two days	Lden in dB(A)	Ld in dB(A)	Le in dB(A)	Ln in dB(A)
CALCULATED	60.5	59.4	56.4	52.1
MEASURED	60.6	58.7	57.4	52.5
difference	**-0.1**	0.7	-1	**-0.4**

Table 8.11 Comparison between measured and calculated values for two days period, measurement pt 1

POINT 2 one day	Lden in dB(A)	Ld in dB(A)	Le in dB(A)	Ln in dB(A)
CALCULATED	62.5	61.8	58.2	53.7
MEASURED	61.9	59.9	60.1	53.4
difference	**0.6**	1.9	-1.9	**0.3**

Table 8.12 - Comparison between measured and calculated values for one day period, measurement pt 2

POINT 2 two days	Lden in dB(A)	Ld in dB(A)	Le in dB(A)	Ln in dB(A)
CALCULATED	61.6	60.8	57.4	52.8
MEASURED	62.1	60.2	59.6	53.5
difference	**-0.5**	0.6	-2.2	**-0.7**

Table 8.13 - Comparison between measured and calculated values for two days period, measurement pt 2

The values calculated referring to the day and evening and period differ of a maximum of 1.5 dB for the first points and of 2.2 dB for the second point. However this discrepacy is lowered in the L_{den} and L_{night} calculation, that are the indicators required by the law.

It is possible to notice that the difference between L_{den} calculated by the model is about 0.7 dB higher than the measured one when the simulation accounts for the single day traffic flow. The second type of verification provides even better results. If the reference period is referred to two days of measurement and the annual mean traffic data the model difference lows down to 0.5 dB or even 0.1 dB(A). The model tends to slightly underestimates the noise level, however, the discrepancy is very low, and basically inexistent for point 1.

The difference between the computation and the measurement of L_{night} is about 0.7 dB(A) for point 1 and from 0.3 to 0.7 dB(A) for point 2. Even in this case, for the reference period exended to two days of measurement and the annual mean traffic data the model tends to slightly underestimate the noise level.

Although the verification has been performed for a simplified situation in terms of geometry, noise source type and traffic data, a discrepancy between calculated results and measured ones arises.

To evaluate the reliability of the model it is necessary to consider the purpose of the study. When a detailed study is performed on a specific area, the goal is to reduce the differences between measured results and simulated ones in order to better describe the actual situation of the given area. Calibration is done modifying traffic flow data, the ground absorption coefficients, correcting the geometry of the model etc. The purpose is to make the model as much as possible corresponding to the state of the art before the isertion of a noise reduction measure. Thus the effectiveness of the measure can be computed comparing the two simulations before and after works. For this purpose the uncertainty should be restrained to 0.5 dB(A). A detailed study would need more measurement campaigns and a different approach that does not fall into the purposes of this project.

The purpose of the project is to obtain a description of the global situation of an huge area. To do so the response of the model has been investigated. The goal is to prove that, if traffic data are reliable, the model response is acceptable. This is valid for situation not too complex, for example it is not valid for those areas in the proximity of roundabouts, junctions and bridges. The calibration performed can be considered a general validation of the parameters chosen for the model to describe the noise source. A further refinement of the model would have brought to a perfect calibration for the specific location where the measurements have been done, but on the other side would have not improved the overall accuracy of the study. From this point of view the order of magnitude of the uncertainty is not only acceptable, but can be also considered a good result. In fact for this type of study discrepancy of 2-3 dB(A) are frequent and usually admitted.

Thus, the calculation model is reliable as long as input data can be considered reliable.

9 RESULTS

As previously discussed in chapter 4, there are several types of results representations, according to the type of indicator chosen, for example L_{den} or L_{night}, the type of output, like graphics or tables. The purposes of the map also influences the choice of the map itself. In the studied case, two main types of maps have been chosen.

9.1 NOISE MAPS

The first type of maps consists in a noise maps, that is to say a graph where the noise indicator L_{den} or L_{night} is represented by colored areas according to the levels obtained from the calculation, divided by multiples of 5 dB. The map covers the studied area, and can indicate also the noise source and the receivers.

The legislation requires the study of each road arch separately. Thus, simulation have been implemented to reach this type of results. Here is reported an example of the study that has been carried out for all the 27 road sections analyzed.

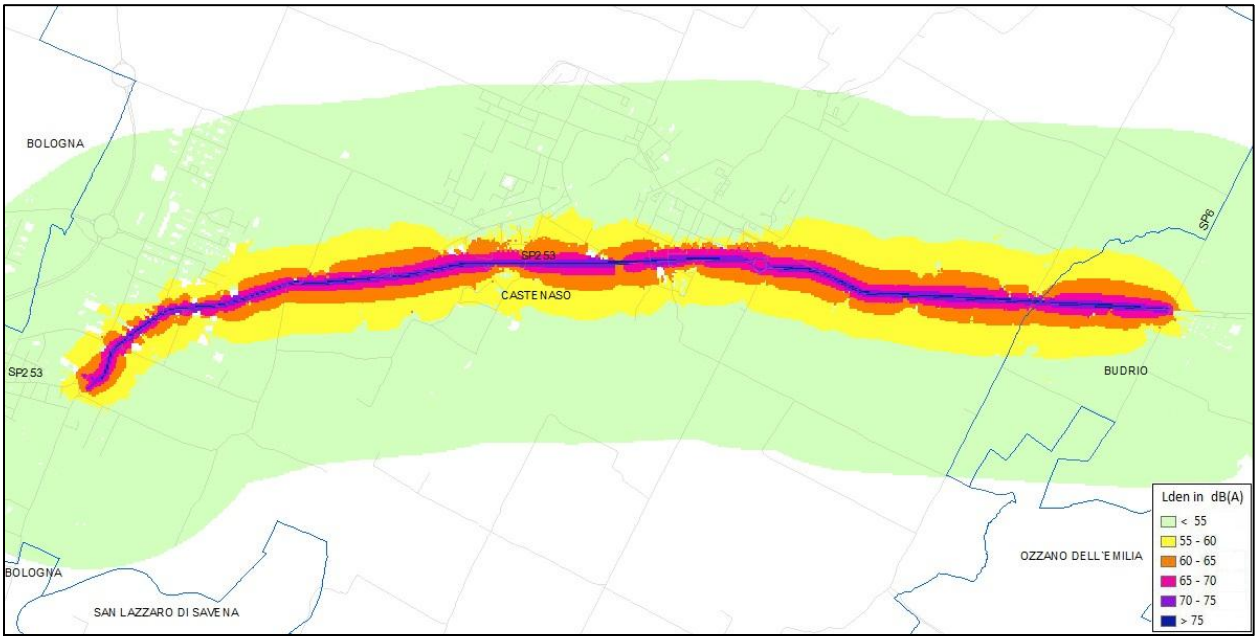

Figure 9.1 -Noise map of Lden level for the road arch belonging to SP253 San Vitale.

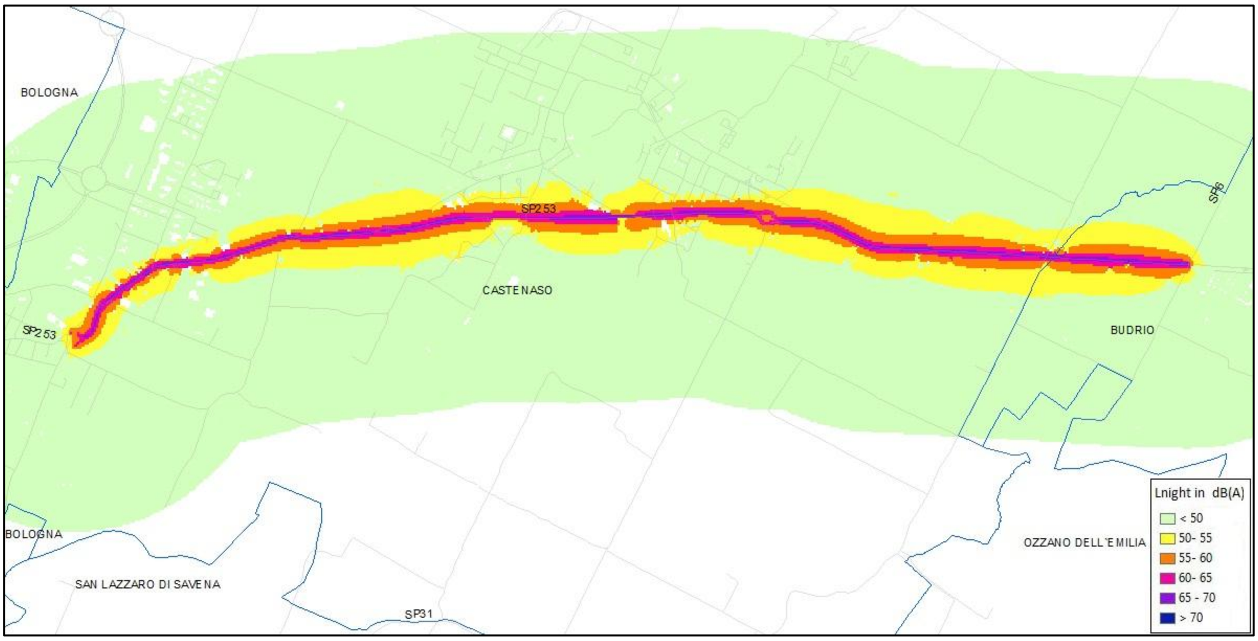

Figure 9.2 - Noise map of Lnight level for the road arch belonging to SP253 San Vitale

In order to make global considerations the analysis has been enhanced to the entire studied area. For this purpose, from the results obtained for each road section, a particular procedure has been implemented to obtain global results without the necessity of performing another simulation in SoundPLAN.

The procedure focuses on the parts of the buffer area of each road arch that overlap the buffer area of another road arch. This happens where two or more sections intersect or where road arch are contiguous. The calculation accounts for the superposition of the effects aroused by the different road arches. In fact in these case it is necessary an energetic sum of the noise levels according to the formula:

$$L_{TOT} = 10log\left(\sum 10^{\frac{L_i}{10}}\right) \text{ in dB}$$

Where L_i is the max noise level in dB generated by the i-th road arch.

The possible local error at junctions is negligible, in fact in this type of modeling, junctions and in particular roundabouts are already approximated. Particular driving patterns with specific accelerations and decelerations in proximity of the junction are neglected. Such detailed modeling would be very time consuming and not significant for the purposes of the study.

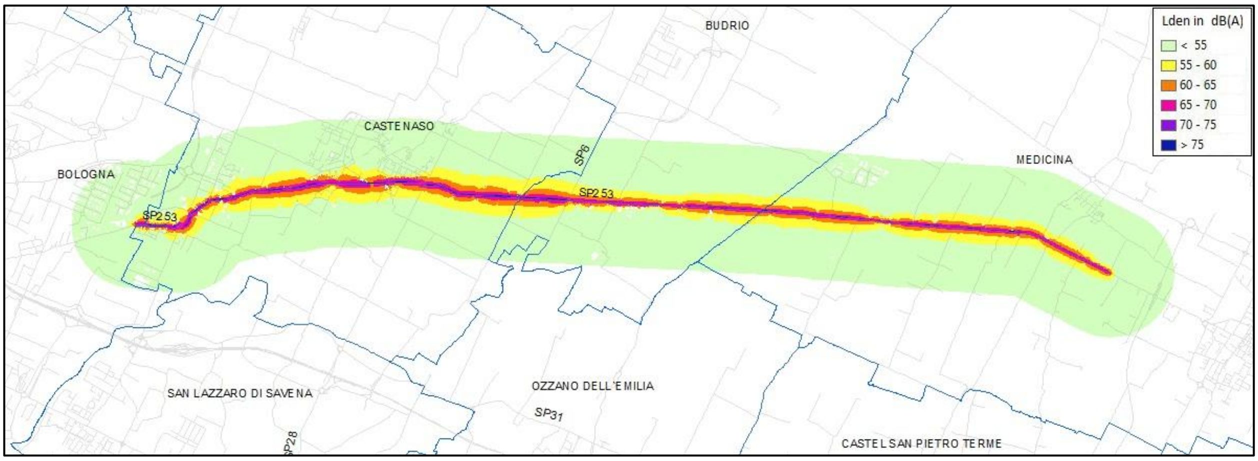

Figure 9.3- Noise map of Lden level for the three road arches belonging to SP253 San Vitale

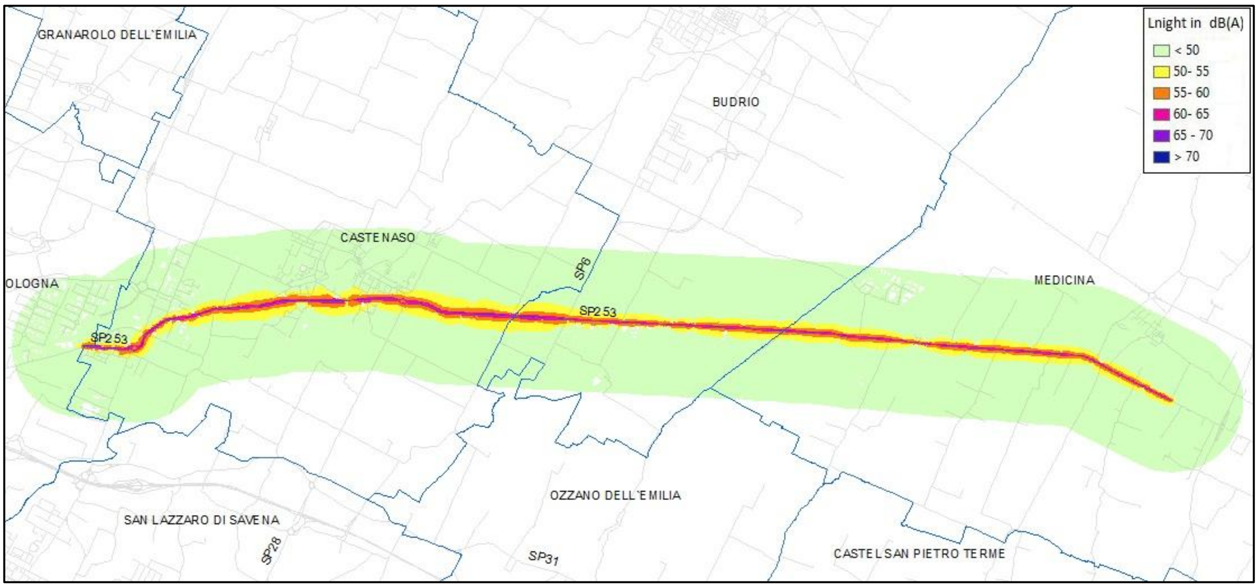

Figure 9.4 - Noise map of Lnight level for the three road arches belonging to SP253 San Vitale

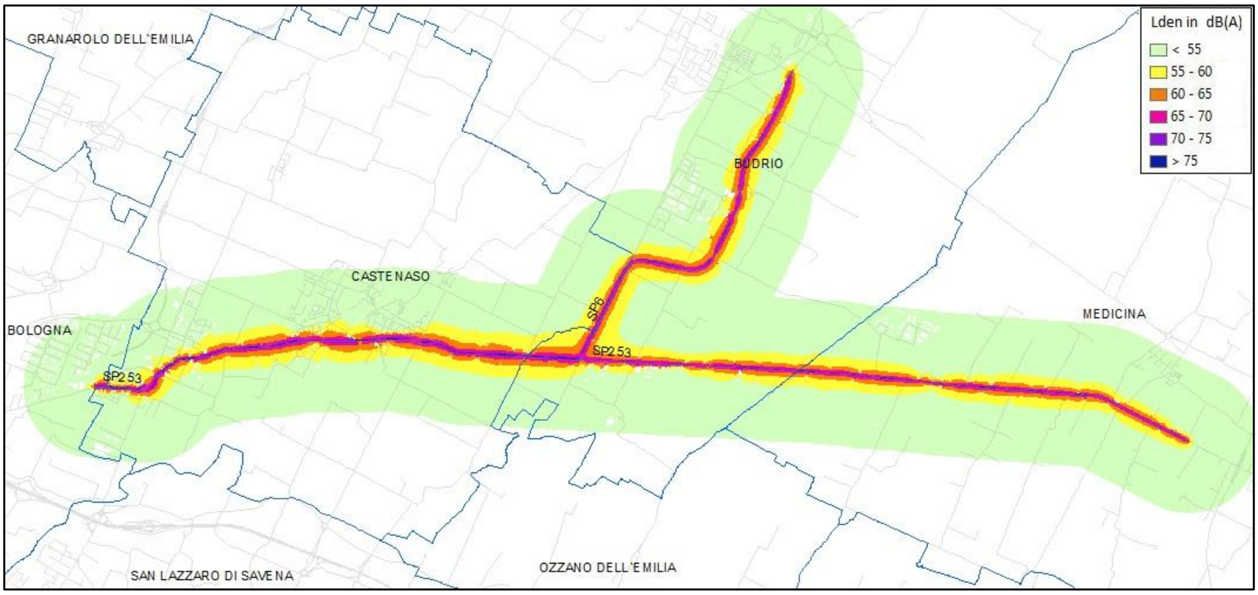

Figure 9.5 - Noise map of Lden level for the sections of the roads SP253 and SP6

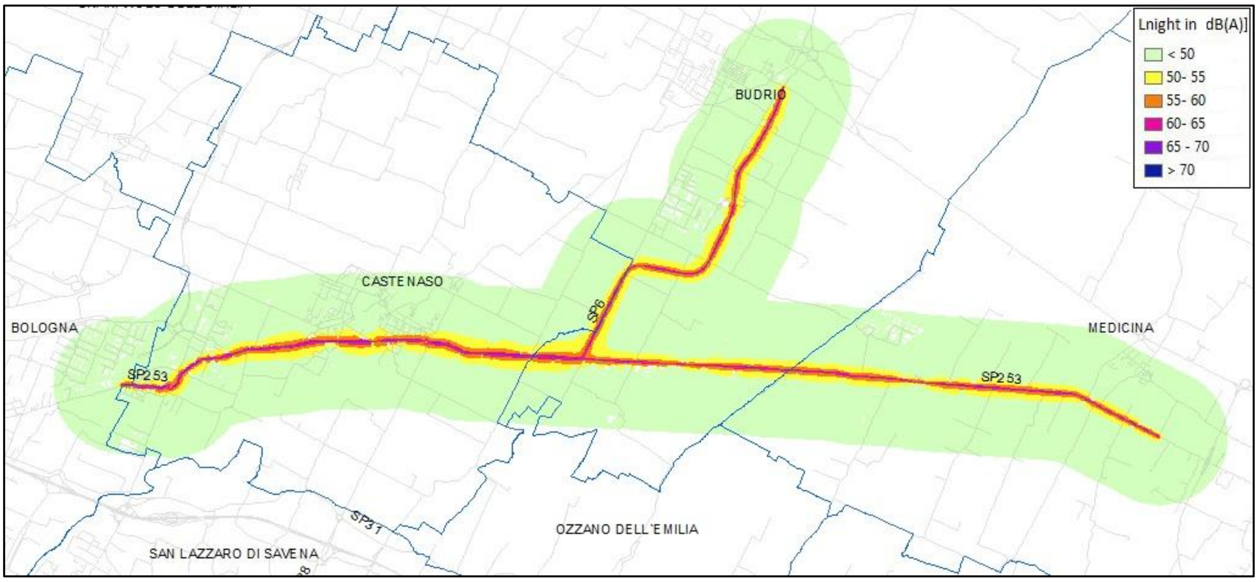

Figure 9.6 - Noise map of Lnight level for the sections of the roads SP253 and SP6

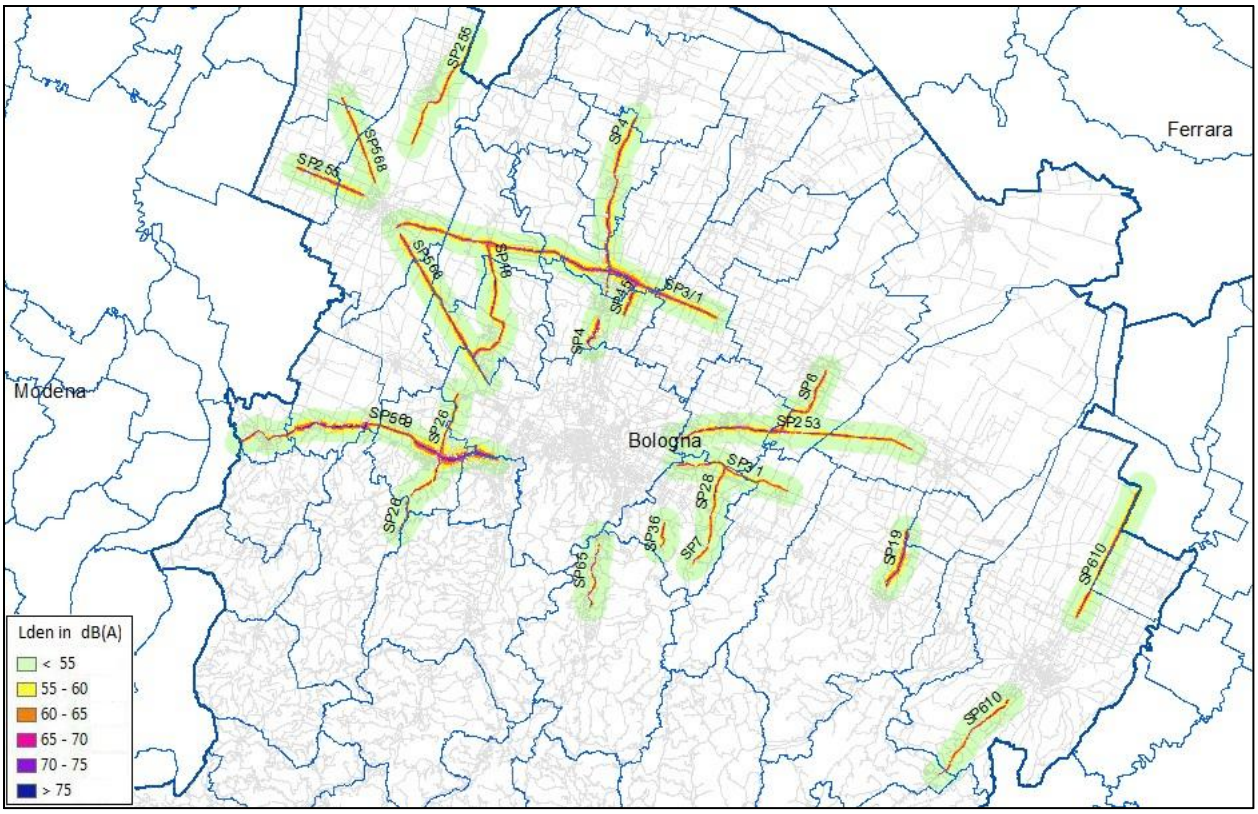

Figure 9.7 - Noise map of Lden level for all the studied road sections of the Province of Bologna

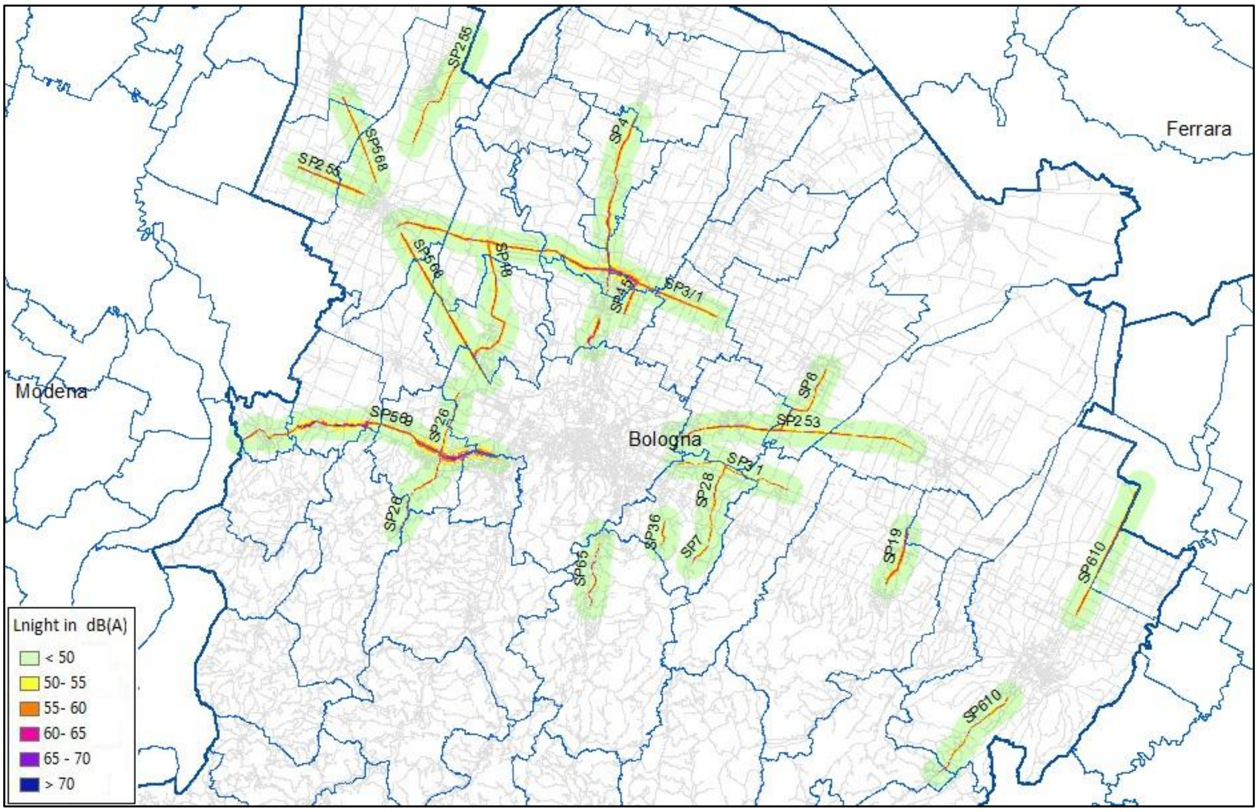

Figure 9.8 - Noise map of Lnight level for all the studied road sections of the Province of Bologna

Considering together the road arches belonging to the same provincial road might be helpful to identify areas where noise levels are higher. In the figure 9.3 and 9.4 it is easy to notice that the part of the road crossing the town of Castenaso is the most critical area. L_{den} and L_{night} are higher. In the same way taking into account for the overall road arches lead straightforward to the identification of the areas where noise levels are higher, for example where SP 569 and SP 26 overlap and where SP3/1 and SP 45 overlap as it is shown in figure 9.5 and 9.6.

This might be an useful tool for approaching the noise issue, especially at early stages of noise abatement measures planning. However it is important to keep in mind that noise levels do not represent a thorough way to investigate criticalities because the amount of people exposed is not taken into account.

In the next chapter a more complete and effective way to analyze the noise criticalities considering both noise levels and number of people exposed will be presented.

9.2 EXPOSURE MAPS

The second type of maps has the purposes of showing the number of people exposed to certain levels of noise indicators L_{den} and L_{night}. It is represented by a table that indicates the number of inhabitants for each noise level by interval of 5 dB.

In this case the maximum noise level among those calculated for each building façade has been selected. The number of residents has been assigned to each dwelling according to demographics data.

Similarly to the previous case, the legislation requires the number of people living in dwellings exposed to determined noise levels for each road section.

The study has been implemented in order to obtain general results that might be more interesting to analyze. The procedure performed accounts for the superposition of the effects of different road sections. Where adjoining buffers intersect, noise levels have been sum up energetically.

The procedure consisted in joining into a unique shapefile all values recorded for each building façade, with different recording value in case of superimpositions. In case of void intersections, values of L_{den} and L_{night} equal to zero have been assigned. As noise level sum up energetically this means that a value equal to zero increases the global value but actually the increase is so small that is negligible.

Thereafter the maximum value of the façade noise levels and the number of resident have been assigned to the correspondent building. Attention has been paid to compute population only for residential dwellings as requested by the law. Finally the total number of resident exposed to determined noise levels has been obtained. Results are reported below.

Lden in dB	Number of people exposed	% population of the studied area	Lnight in dB	Number of people exposed	% population of the studied area
<55	135269	84.1	**< 50**	141630	88.0
55-60	10014	6.2	**50-55**	7731	4.8
60-65	6424	4.0	**55-60**	5720	3.6
65-70	5331	3.3	**60-65**	5005	3.1
70-75	3771	2.3	**65-70**	838	0.5
> 75	128	0.1	**> 70**	14	0.0

Table 9.1 - Number of people exposed to L_{den} and L_{night} levels

From the table it is possible to know the number of people exposed to noise levels with respect to the total number of people that live in the proximity of the provincial roads, that is to say the number of people living into the buffer area of 1 km from the noise sources considered.

As it has been explained in capter 5.5, data are obtained from the ISTAT, (Italy's National Statistics Institute) referring to Emilia Romagna Region (R08) for the year 2011 [26]. The number of people for each building has been assigned on the basis of an automatic procedure on the ArcGIS software allocating the residents for each sections to the dwellings belonging to the section itself according to the volume of buildings. For the buffer area considered the total amount of people is **160937**.

It can be seen that L_{den} levels are acceptable for more than 80% of the population but almost 4000 residents are exposed to levels exceeding 70 dB(A) in which more than 100 are expose to more than 75 dB(A). L_{night} levels are acceptable for more than 88% of people but 852 residents are exposed to Night time period noise levels higher than 65 dB(A).

9.3 INFORMATION TO THE PUBLIC

Article 1(b) of the END states that:«Ensuring that information on environmental noise and its effects is made available to the public» [1]

In Article 9.2 of the END it is required that: «This information shall be clear, comprehensible and accessible. A summary setting out the most important points shall be provided.» [1]

Two main purposes for the information to the public can be considered according to WG-AEN Presenting Noise Mapping Information to the Public [17]. They are listed below.

- Purpose 1 is to inform the public of the results of strategic noise mapping at local and national level and at the same time explain how this information relates to them.
- Purpose 2 is to start to engage the public in the process of developing action plans since these plans should be based on the results of the strategic noise maps and should in particular apply to the most important areas as established by the maps. The purpose of these action plans is to prevent and reduce environmental noise, where necessary and particularly where exposure levels can induce harmful effects on human health, and to preserve environmental noise quality where it is good, for example in so-called quiet areas.

Information to the public should guarantee some basic requirements to make it effective. The Emilia Romagna Region Guidelines [23] provide a list of requirements that is briefly listed above.

Communications should:

- be clear, understandable and accessible;
- underline major aspects of noise mapping;
- include the partition into territorial areas (Municipalities, Provinces, Regions);
- include different levels of the analysis and possibly a summary;
- indicate data sources and reference period;
- be diffused in a coherent way;
- envisage feed-back procedures from the different types of data and public;
- be free;
- be rapidly available and periodically updated;

The END requires also that the most appropriate information channels should be selected. Information channels may inlude [23]:

- tradition data types;
- electronic data supports as web, CD, DVD
- websites of the Administration;
- websites of environmental agencies (ARPA, ISPRA);
- brochures;
- public debates and presentations.

10 PRIORITY INDICATORS

According to END [1] two main tools are used to deal with the noise issue. The first tool is the noise mapping, the second one is the action plan. The latter is used to move from information obtained through noise mapping to noise abatement.

Priority indicators underlie the action plans. The goal is to identify and prioritize areas where interventions are needed.

In the previous chapter the results of the noise mapping have been presented. Information such as levels of the noise indicators and the number of people exposed to certain noise levels has been obtained.

In this chapter a further analysis will be carried out. In fact to study criticalities it is important to consider not only noise levels and limit exceedance, but also to couple information with the number of people exposed. Priority indexes should account for both noise levels and population exposed.

10.1 CRITICALITY INDEX *P*

The preexistent Italian Legislation with the D.M.29/11/2000 [8] specifies a criteria called "*indicatore di criticità P*" (criticality index P). This index, however, is appropriate for simple cases with few infrastructures and almost homogeneous areas, but it is not practicable for complex situation like urban agglomerations.

In Annex 1 of the D.M. 29/11/2000 [8] the criticality index P is defined as:

$$P = \Sigma\, R_i\, (L_i - L_{*i})(I)$$

where:

A is the studied area subdivided in sub- areas A_i so that $A_i = A$;

R_i is the number of exposed people for the area A_i calculated on the basis of the most updated demographic data, for hospitals, the number of beds is to multiply by 4, for schools the number of students is to multiply by 3;

L_i is the equivalent sound pressure level for the reference period, generated by the infrastructures of the area A_i, considering for each building the value of the most exposed façade. The variability of L_i within A_i should not be greater than 3 dB(A);

(I) is the central value of the interval;

L_{*i} is the limit value of immission.

It is equivalent to:

L_{*izone} that is the limit value according to the acoustic zoning or

$L_{*istrip}$ that is the limit value of the strip of pertinance of the infrastructure according to the D.M. n.142/2004 [9]. If the area is in correspondence of two or more strips the greatest limits are to be considered.

For $(L_i - L_{*i}) < 0 \rightarrow (L_i - L_{*i}) = 0$

10.2 CONSIDERING THE STRIPE OF PERTINENCE

In the table below are listed the limits for existing roads according to the road type given by the D.M. n.142/2004 [9].

TABLE 2: Existing roads or similar		Sensitive receptors		Other receptors	
Tipo	Stripe Width (m)	Day	Night	Day	Night
A	100 Stripe A	50	40	70	60
	150 Stripe B			65	55
B	100 Stripe A	50	40	70	60
	150 Stripe B			65	55
C / Ca	100 Stripe A	50	40	70	60
	150 Stripe B			65	55
C / Cb	100 Stripe A	50	40	70	60
	150 Stripe B			65	55
D / Da	100	50	40	70	60
D / Db	100			65	55
E	30	Defined by municipalities, based on local zone divisions.			
F	30				

Table 10.1 - Stripes of pertinence and noise limit values for existing roads. [9]

In the studied case SP 253 San Vitale corresponds to a road type Cb with limits of L_{Aeq}, equivalent sound pressure level A-weighted, respectively for day period (06-22) and night period (22-06) of 70 dB(A) and 60 dB(A) for strip A, equal to 100 meters from the linear infrastructure and 65 dB(A) and 55 dB(A) for strip B, equal to 150 meters from the infrastructure. From a practical point of view, with a simple calculation it is possible to transform the values of L_{Aeq} for day and night period into values of noise indicator L_{DEN}.

10.3 LIMITS OF THE METHOD

The method is applicable for simple cases with few infrastructures and homogeneous areas, whereas it gets more and more unsuitable for more complicated cases as urban agglomerates.

Some limits are imposed by the randomness in the combination of areas A_i for which the variability of noise level is lower than 3 dB(A). This influences the criticality index P and consequently the decisional process. Solutions to this problem are suggested in the Regional Guidelines [23], but it is also underlined the difficulty to implement them in the calculation program.

10.4 PRIORITY INDEX ECU_{den}

At the European level, the END does not enforce a specific criticality indicator. However the European Community proposes an updated version of the Belgian criteria called ECU_{den} (Exposure Comparison Unit), that is more actionable and less random with respect to the Italian one.

In the Good practice guide on noise exposure and health potential effects [18], the updated version of the ECU_{den} has been called $L_{den,dwellings}$ or $L_{den,population}$ referring respectively to dwelling exposure or to population exposure. These overall indicators can be used to rank situations in order to prioritize action plans.

The formula is:

$$ECU_{den} = 10\log\sum_{i=1}^{N} 10^{\frac{L_i+L_c}{10}} \quad in\ dB$$

Where:

N is the number of residential dwellings or the number of residents, an option has to be chosen, in an area.

L_i is the exact value of L_{den} of the most exposed façade of the i-th dwelling or of the dwelling where the i-th resident lives, an option has to be chosen.

In both cases only values of $L_{den} > 55$ dB have to be considered.

L_c is the correction factors for sensitive receivers and is equal to:

+ 5 dB (A) for schools

+ 10 dB(A) for hospitals.

To determine areas the following procedure is suggested:

First the infrastructures are divided in sectors of length of 100 m along the center line.

For each sector the value $ECU_{den,100m}$ is computed. For sectors with $L_{den} > 55\ dB$, $ECU_{den,100m} = 0$.

Secondly the adjoining sectors with $ECU_{den,100m} > 0$ are joined in a unique site and $ECU_{den,site}$ is computed with logarithmic mean.

Thirdly sites are divided in four categories depending on the value of L_{den} and they are listed according to the decreasing value of $ECU_{den,site}$. At each list is assigned a priority index.

High values of $maxL_{den}$ are intended > 65 dB, high values of $maxL_{night}$ are > 55 dB.

$ECU_{den,site}$	$maxL_{den}$ and/or $maxL_{night}$	**Priority**
High value	High values	Case 1: urgent improvements required
Low value	High values	Case 2: improvements on façades required
High value	Low values	Case 3: low priority
Low value	Low values	Case 4

Table 10.2 - Priority assignement for linear infrastructure [23]

10.5 PRACTICAL PROCEDURE

The method suggested for the computation of the ECU_{den} for linear infrastructure would imply a complicated procedure to implement the software calculation. It has been considered more convenient to compute the ECU_{den} referring to regular areas of a grid according to Emilia Romagna Region Giudelines [23], where:

N is the number of residents for the single dwelling;

L_i is the value of L_{den} of the most exposed façade of the dwelling where the i-th resident lives; only values of $L_{den} > 55\ dB(A)$ are considered;

ECU_{den} is calculated for each dwelling;

each ECU_{den} calculated is aggregated by areas of dimensions 100m x 100m, resulting from the superposition of an ideal grid on the portion of territory considered.

The computation has been performed on the road arches that compose the studied part of provincial road n.253 *via San Vitale*.

Particular attention has been paid in converting polygons of buildings in centroids, to avoid problem in assigning the identity of the specific area on the grid. Moreover, ECU_{den} has been calculated only for the use categories required by the method, in practice only category "*abitativa*", residential, corresponded to the requirements. Computation has been performed for $L_{den} > 55\ dB$. Assigned number of residents < 1, due to the method of residents allocation that refers to volumes of the dwelling, has been approximated to 1.

Priority indicators are relatively recent, thus there is not yet a common scale of criticalities. For this study, the scale of the priorities provided in the first cycle of elaborations for the Bologna agglomeration has been considered. The scale has been deduced on statistical analysis, based on the experience of the specific situations studied.

ECU_{den} *in dB*	**Criticality**
≤ 60	Acceptable
60-70	Moderate criticality
70-80	Criticality
≥ 80	Severe criticality

Table 10.3 Priority assignement according to the procedure suggested in the regional guidelines [23]

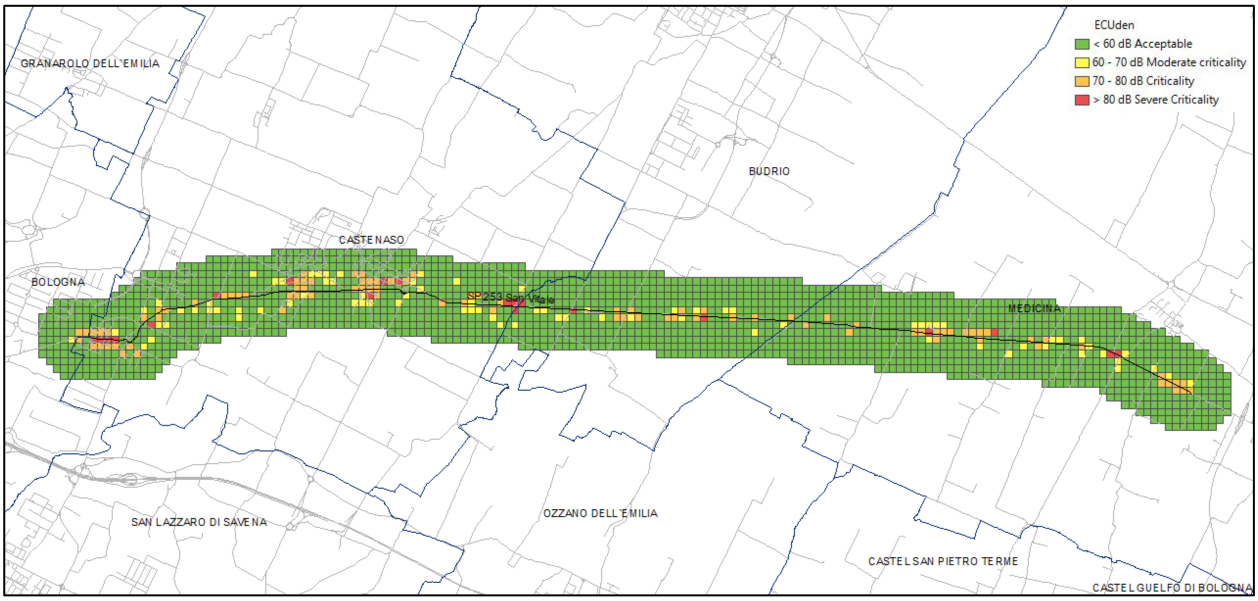

Figure 10.1 - Priority map of the sections of the SP 253

Figure 10.2 - of the sections of the SP 253

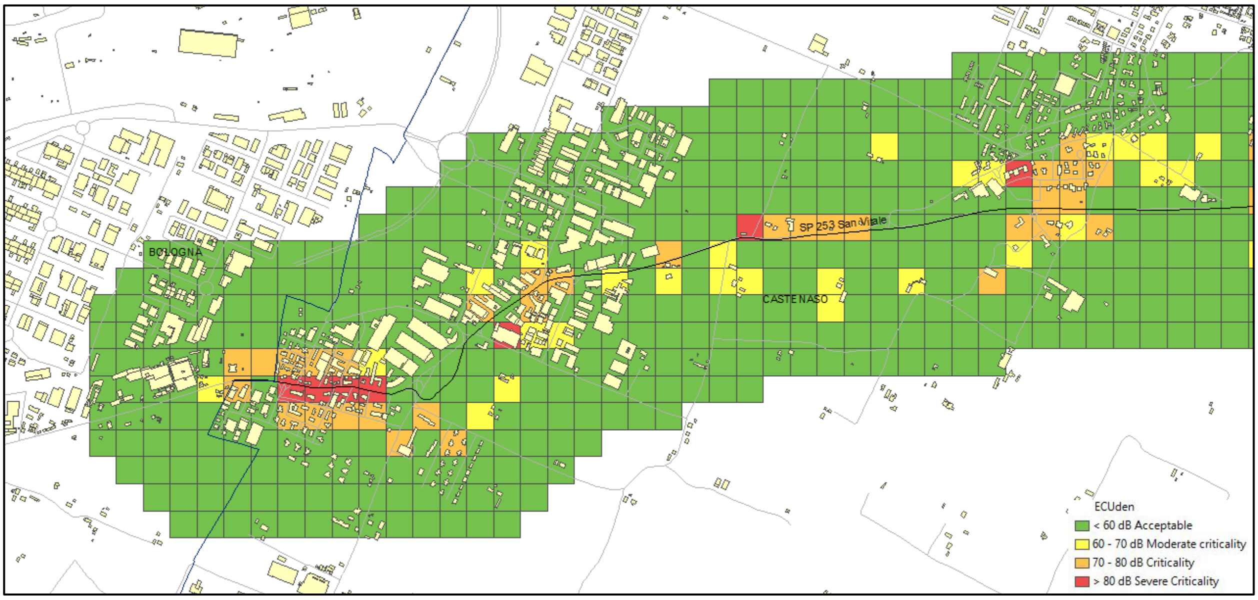

Figure 10.3 - ECUden of the sections IT_a_rd0062013 and IT_a_rd0062025

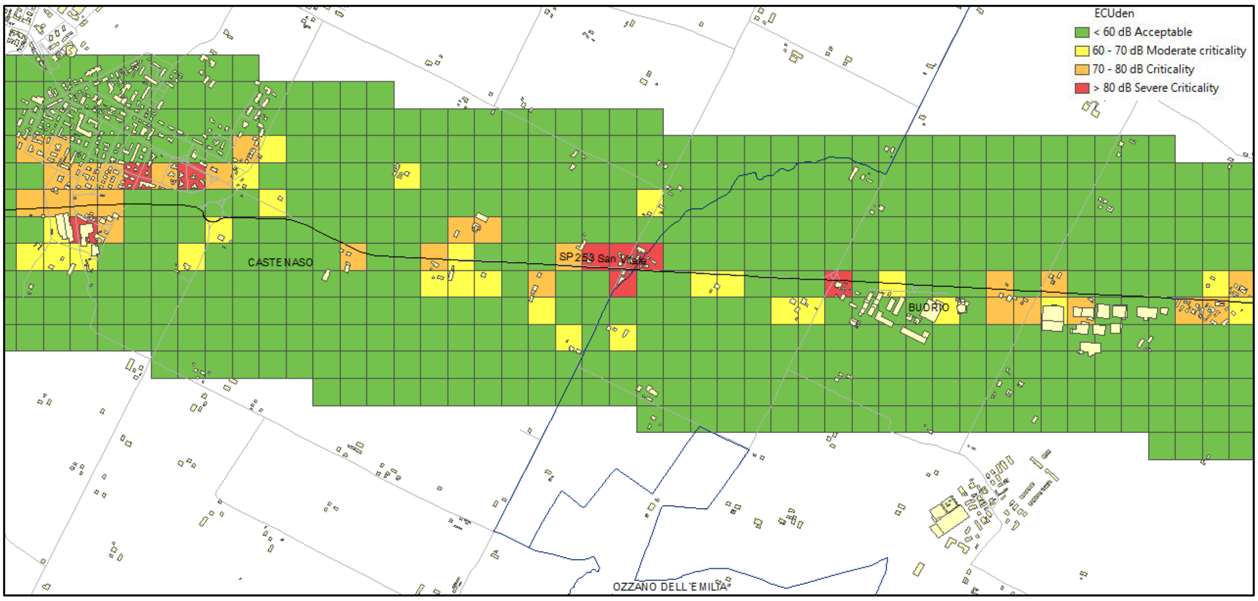

Figure 10.4 - ECUden of the section IT_a_rd0062025

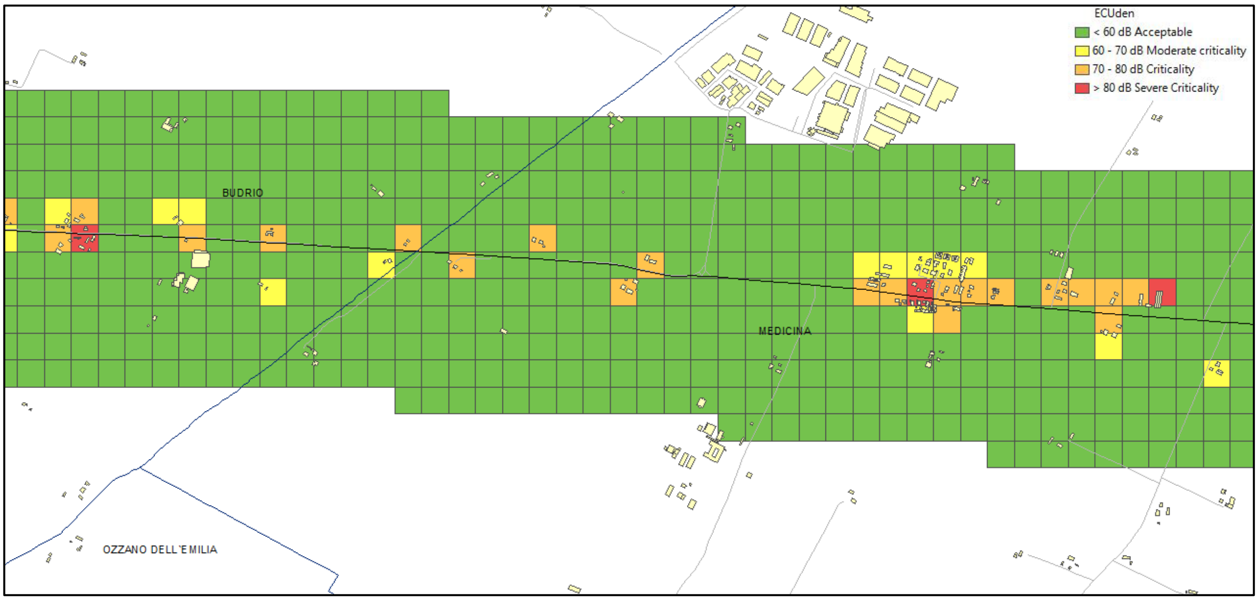

Figure 10.5 - ECUden of the section IT_a_rd0062025

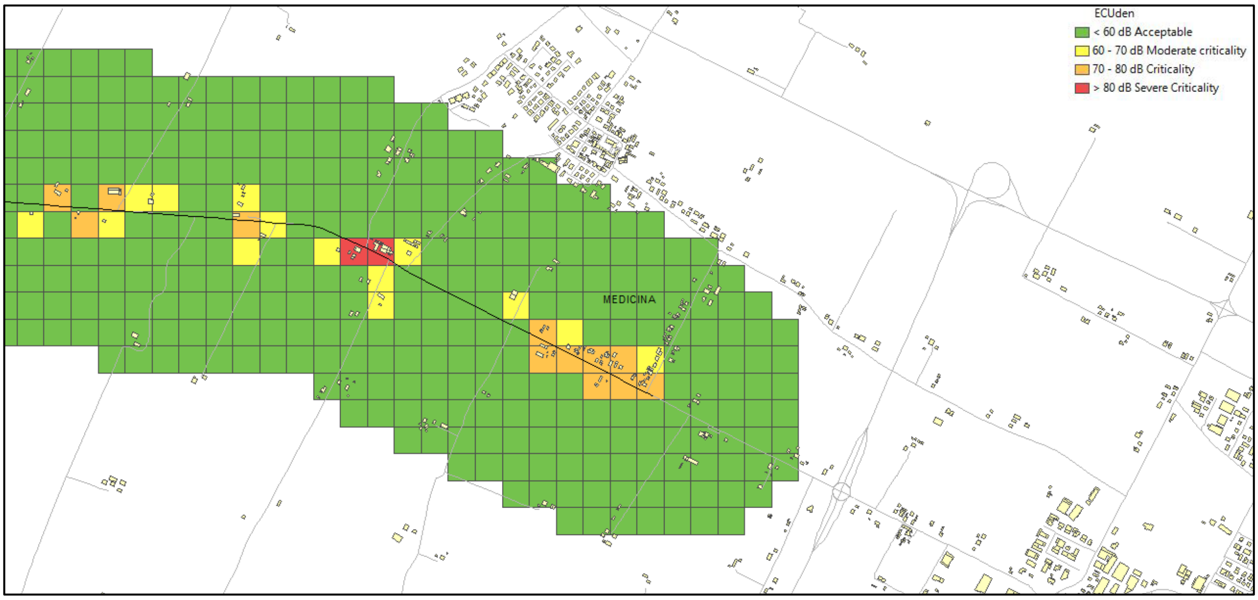

Figure 10.6 - ECUden of the sections IT_a_rd0062025 and IT_a_rd0062014

10.6 CONSIDERATIONS

The map has been calculated with a grid of 100 x 100 meters and a buffer of 500 meters from the road line. From the maps it is easy to notice that criticalities are present for a maximum distance of 300 meters from the road. The majority of the critical areas belongs to the Municipality of Castenaso, followed by Medicina and Budrio.

There are 20 grid cells in red corresponding to severe criticality, 91 in orange and 80 in yellow corresponding to moderate criticality. Area of severe criticality are sparse with the exception of three areas:

- at the border between the Municipality of Castenaso and the Municipality of Bologna, in the road section IT_a_rd0062013, where four connected grid cells are red;
- at the border between the Municipality of Castenaso and the Municipality of Budrio in the road section IT_a_rd0062025, where four connected grid cells are red;
- in the Municipality of Medicina in the road section IT_a_rd0062014, where two connected grid cells are red.

From this type of representation the recognition of the most critical areas is straightforward. Thus the process is at the basis of the development of the action plan aiming to the mitigation of the noise to protect people's health and improve quality of life in urban areas. The action plan implies setting priorities and scheduling the implementation of measures over a short, medium and long-term period.

Several noise mitigation techniques are available nowadays referring to four different categories:

- Measures to avoid and reduce noise at its source.
- Measures to reduce the propagation of noise.
- Measures on the relative distance between source and receiver.
- Measures to reduce noise at the receiver.

The structure of the action plan, noise abatement strategies and hierarchy of interventions are discussed more extensively in the appendix "Noise abatement measures".

10.7 STUDY OF A CRITICAL AREA

It has been considered the area with four connected cells of severe criticality at the border between the Municipality of Castenaso and the Municipality of Bologna, in the road section IT_a_rd0062013.

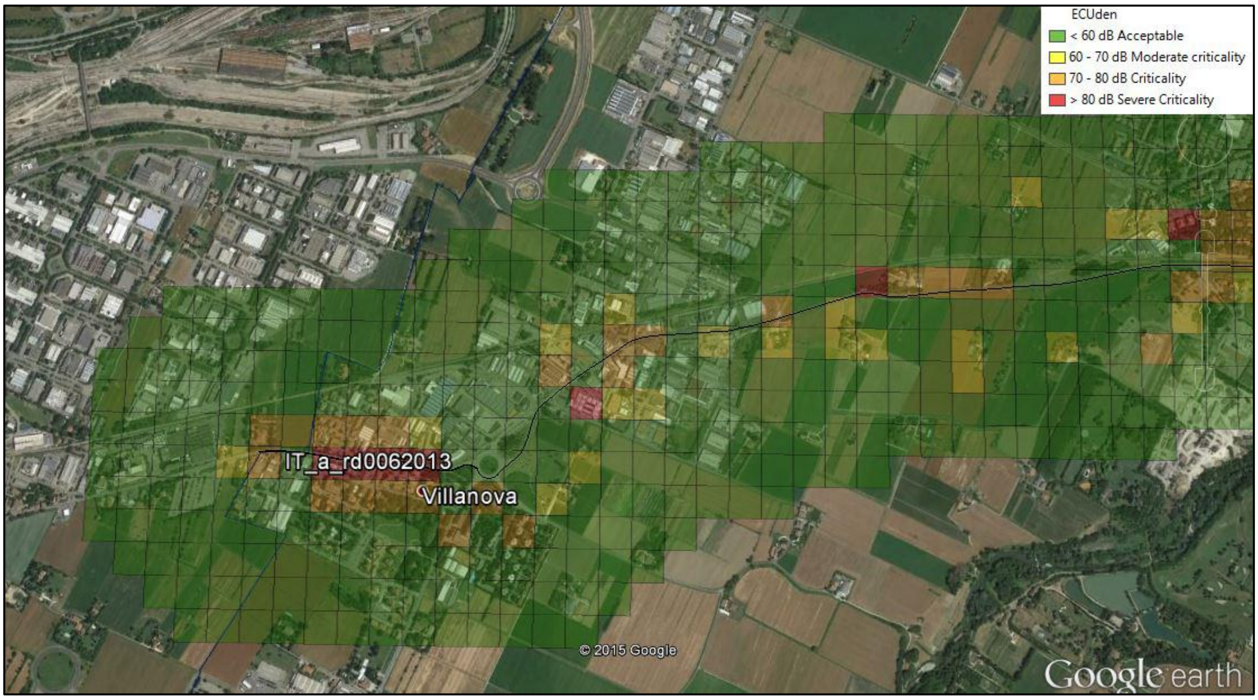

Figure 10.7 - ECUden for the road section IT_a_rd0062013

Figure 10.8 - ECUden for the road section IT_a_rd0062013

Figure 10.9 - Street view of part of the road section IT_a_rd0062013

The road section starts at km 5.777 and ends at km 6.460 and it is characterized by an annual traffic flow between 3 and 6 millions of vehicles. The speed limits is 50 km/h along all the section and the actual speed, the mean distribution of daily transit and percentage of heavy vehicles has been calculated according to the procedure illustrated in chapter 6.

Results are reported in the tables below.

Speed limit 50/60 [km/h]	Day period mean speed [km/h]	Evening period mean speed [km/h]	Night period mean speed [km/h]
Light vehicles	57.9	58.6	60.1
Heavy vehicles	55.7	55.5	59.8

Table 10.4- Mean velocities for day, evening and night period related to speed limits of 50 and 60 km/h

% day period transits	% evening period transits	% night period transits
84.33	6.94	8.73

Table 10.5 - Mean distribution of daily transits according to data source (a)

% heavy vehicles day period	% heavy vehicles evening period	% heavy vehicles night period
6.83	2.67	7.82

Table 10.6 - Mean percentages of heavy vehicles for day, evening and night period according to data source (a)

10.8 EXAMPLE OF POSSIBLE SOLUTIONS

Measures to avoid and reduce noise at its source:

a) Low speed limit or enforce actual speed limit.

Although the speed limit is already low from the study emerged that in general drivers do not respect it. In fact velocities accounted in the computation are higher than the limit. A detailed study on the area could assess if the limit is respected. If not measures to enforce it as variable signs or police controls. Otherwise a further decrease might be considered. Particular attention should be payed to the driving pattern (accelerations and decelerations) that can greatly influence noise generation. In general reducing the speed will also contribute to road safety and improved air quality.

b) Change traffic composition.

A change in traffic composition, decreasing the percentage of heavy vehicles might also reduce the noise. Possibilities are bans on trucks and the design of alternatives paths. In this case the feasibility of the solution should be studied carefully.

c) Low noise surfaces.

The use of low noise surfaces as porous asphalt or double layer porous asphalt can be considered.

Measures to reduce the propagation of noise:

d) Traffic barriers.

Traffic barriers offer a huge variety of solutions in terms of materials and aesthetics. A proper shape (length and height) and position should be design in order to make the barrier effective. The barrier should not interfere with road safety.

It is important to underline that each intervention should be preceded by detailed studied of the critical areas that include specific surveys and simulations comparing the state of the art and the effects of the suggested solution.

It is also possible that during the detail studies some solutions result more convenient than other also accounting for different aspects other than acoustics, for example air quality, road safety and congestion, energy consumption etc.

11 CONCLUSIONS

Here are pointed out some of the main aspects of the process and the choices that have been made for the noise mapping.

The legislation requires the use of harmonized indicators L_{den} and L_{night}. These are different from those indicated by the Italia law in the decrees D.M. October 31st 1997 [4] and D.P.C.M. November 14th 1997 [5], implementing the Law 447/95 [3], that define respectively the airport noise indicators LVA and the continuous equivalent sound level corrected with weighting curve A, $L_{A,eq}$ for the other noise sources. $L_{A,eq}$ is referred to day period from 06 a.m. to 11 p.m. and to night period from 11 p.m. to 06 a.m. This, however, did not constitute a problem, in fact that the Law 447/95 [3] states that national limit values will be translated according to European limit values. Despite the fact that there is not a law implementing it yet, the conversion is possible. For this reason it has been chosen to use directly the European indicators L_{den} and L_{night}, converting the national limit values.

An aspect that influences both the accuracy and the validity of the results is the data collection. There were several data sources available, but the different origins have brought some discrepancies that have to be overcame through analysis and comparison. Moreover not all the types of data available refer to the time period of 2011. In this case the most updated data have been chosen.

Data regarding the digital ground model, the buildings and the administrative data have been obtained mainly from the DBTR that is the Emilia Romagna Region topographic base and provides high quality data that are easy to access. The ground factors have been selected using the cartographic covering of land use of year 2011 that combines information of the CLC2000, Corine Land Covering 2000, and national specifications. Demographic data have been obtained by ISTAT [26] (Italy's National Statistic Institute), while meteorological data have been obtained use default values given in the toolkit 17of the Good Practice Guide [16], as national standards do not exist in Italy. The spatial definition of the noise sources has been provided by the Informative Territorial System of the Province of Bologna [28].

For noise source emission data many different typologies of data were available. Data have been provided by the Region, the Province of Bologna and ANAS SpA, national roads department. Confrontation and elaborations were necessary to assess number of transits and allocation during the day, evening and night period, velocities and percentage of heavy vehicles.

The calculation method indicated by the D.Lgs. 194/2005 [10] in attachment 2 has been used, as Italy does not have national methods. It is the official French Method NMPB-Routes-96

(SETRA-CERTU-LCPC-CSTB), mentioned in «Arrêté du 9 mai 1995, relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1996, article 6» [31] and in the French standard «XP S 31-133». For the emission input data the documents refer to the «Guide du Bruit de Transports Terrestres du Novembre 1980».

The method has been implemented in the software SoundPLAN that satisfies all the minimum requirements listed in the guidelines AR-INTERIM-CM [15]. In particular the software searches propagation rays with a sector method. Scanning triangles start from the receiver to find sources, reflections, screens and geometry modifying the ground attenuation. When a source is found, the part of the source contained in the search triangle is automatically calculated and processed.

Calibration is a fundamental aspect to define the validity of the model. It is the comparison of the model results with measurements and it is the tool to restrain and reduce uncertainties. The methodology for the global calibration of the model of a given area has been simplified into a punctual calibration. The discrepancy between calculated values and measured ones is fundamental. Unfortunately, for the studied case, there were neither experimental data available nor allocated budget for further measurements. Nevertheless, in order to check in some way the response of the model, a short phonometric survey has been performed. Considering the purpose of the study that is to obtain a description of the global situation of an huge area, the response of the model has been investigated. The goal is to prove that, if traffic data are reliable, the model response is acceptable. This is valid for situation not too complex, for example it is not valid for those areas in the proximity of roundabouts, junctions and bridges. The calibration performed can be considered a general validation of the parameters chosen for the model to describe the noise source. The order of magnitude of the uncertainty obtained that is less than 0.7 dB(A) can be considered a good result. In fact for this type of study discrepancy of 2-3 dB(A) are frequent and usually admitted. Thus, the calculation model is reliable as long as input data can be considered reliable.

Results have been obtained in the form of noise contour maps for L_{den} and L_{night} indicators. As requested by the D.Lgs. 194/2005 [10] for each road section noise contour maps have been provided. In order to obtain a general understanding of the studied area from the results obtained for each road section, a particular procedure has been implemented to obtain global results without the necessity of performing another simulation in SoundPLAN. The calculation accounts for the superposition of the effects aroused by the different road arches. In fact in these case it is necessary an energetic sum of the noise levels. The possible local error at junctions is negligible, in fact in this type of modeling, junctions and in particular roundabouts are already approximated. Particular driving patterns with specific accelerations and decelerations in proximity of the junction are neglected. Such detailed modeling would be very time consuming and not significant for the purposes of the study. Noise contour maps might be an useful tool for approaching the noise issue, especially at early stages of noise abatement measures planning. However it is important to keep in mind that noise levels do not represent a thorough way to investigate criticalities because the amount of people exposed is not taken into account.

Another type of maps required by the D.Lgs. 194/2005 [10] is exposure map. It shows the number of people exposed to certain levels of noise indicators L_{den} and L_{night}. It is represented by a table that indicates the number of inhabitants for each noise level by interval of 5 dB. The study has been implemented in order to obtain general results that might be more interesting to analyze. The procedure performed accounts for the superposition of the effects of different road sections.

Noise contour maps and noise exposure maps might be useful tools for approaching the noise issue, especially at early stages of noise abatement measures planning. However it is important to keep in mind that the noise levels and the number of people exposed do not represent a thorough way to investigate criticalities because the combination of these two aspect should be taken into account. Thus priority maps accounting for both noise level limits exceedance and population exposed should be considered. The goal is to identify and prioritize areas where interventions are needed.

The priority indicator P is defined in the D.M.29/11/2000 [8]. This index, however, is appropriate for simple cases with few infrastructures and almost homogeneous areas, but it is not practicable for complex situation like urban agglomerations. Moreover the correct implementation in the calculation program would be difficult and time consuming. For this reason it has been preferred an updated version of the Belgian criteria called ECU_{den} (Exposure Comparison Unit), called $L_{den,dwellings}$ or $L_{den,population}$ referring respectively to dwelling exposure or to population exposure. This indicators are more actionable and less random with respect to the Italian one.

The criticality has been studied in particular for three section of road SP253 San Vitale in order to show an application of the method. For a specific critical area qualitative solution have been suggested, chosen according to the criteria listed in the appendix "noise reduction measures".

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APPENDIX

ALMA MATER STUDIORUM - UNIVERSITÀ DI BOLOGNA

SCHOOL OF ENGINNERING AND ARCHITECTURE

SECOND CYCLE DEGREE IN CIVIL ENGINEERING

RESEARCH A

IN

ACUSTICA APPLICATA E ILLUMINOTECNICA

NOISE ABATEMENT MEASURES

CANDIDATE:
Giulia Parantelli

SUPERVISOR:
Chiar.mo Prof. Massimo Garai

ASSISTANT SUPERVISORS:
Ing. Luca Barbaresi
Ing. Dario Fattori

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INTRODUCTION

In the context of studying measures for noise abatement it is necessary to consider the various aspects of the noise problem.

Noise is generated by human activities and it has a considerable negative impact on people's quality of life. The relationship between noise exposure and health effects has been widely studied. Noise interferes with communication and it can lead to health effects as sleep disturbance, increase in the level of stress and the risk for high blood pressure and heart attack.

It is important to consider also economical aspects of the noise problem, in fact noise generates costs related to health, for medical treatments, but also other indirect costs for example those related to the decreasing value of houses in noise exposed areas, or costs related to the diminished tax income of the cities because people are abandoning urban areas. [2].

For all these reasons the European Community decided to address to the noise problem and in 2002 the EC promoted the Directive 2002/49, also called the European Noise Directive (END), in order to provide common basis for all European countries to develop common strategies to deal with the acoustic pollution.

THE ACTION PLAN

The Directive indicates two main tools that are complementary: noise maps and action plans.

In the first part of the END noise mapping is defined as a tool to present the noise environment according to certain defined indicators obtaining exceeding limit values and both estimations number of dwellings and number of people exposed to certain noise levels in a given area. From noise maps it is possible to set realistic targets for noise reduction and to provide information to the public.

In the second part of the END the action plan is indicated as a tool to move from information obtained with noise mapping to noise abatement. The scope of the action plan is to protect people's health and improve quality of life in urban areas. This means improving the situation where people are exposed to noise levels that exceeds the established noise thresholds and to preserve those areas where noise limit levels are not exceeded. The action plan implies setting priorities and scheduling the implementation of measures over a short, medium and long-term period. The public should be involved in the preparation and in the review of the action plans and it should be informed about decisions taken. According to the Directive, action plans should include estimations in terms of reduction of the number of people affected by noise and financial information if it is possible (for instance budgets, cost-effectiveness and cost-benefits assessments). [2]

More in details the Directive 2002/49/EC in annex V indicates the elements that the action plans should at least include:

- Description of the agglomeration, the major roads, the major railways or major airports and other noise sources taken into account,
- The responsible authority
- The legal context,
- Any limit values in accordance with Article 5,
- A summary of the result of noise mapping,
- An evaluation of the estimated number of people exposed to noise, identification of problems and situations that need to be improved,
- Record of the public consultation organized in accordance with Article 8,
- Any noise reduction measures already in force and any projects in preparation,
- Actions which the competent authorities intend to take in the next five years, including measures to preserve quiet areas,
- Long-term strategy,
- Financial information (if available): budgets, cost-effectiveness assessment, cost-benefit assessment,
- Provisions envisaged for evaluating the implementation and the results of the action plan.

ASPECTS THAT INFLUENCE THE CHOICE OF NOISE ABATEMENT MEASURES

For studying noise abatement measures it is important to underline some important aspects of action plans that can influence the choices of the measures to adopt.

INVOLVING STAKEHOLDERS

First of all the definition of the responsible authority plays a significant role in the effectiveness of the whole process. In fact the noise problem concerns many different stakeholders. Public authorities are for example: environment authority, urban planning authority, traffic planning authority, land use department, road administration, health administration. On one side it is necessary to define a competent authority and not to spread too much the responsibilities as this could lead to a lack of appropriate actions. On the other side, once the competent authority is identified there should be cooperation between different departments. The same idea applies also for private stakeholders. All the stakeholders should be defined at the beginning of the planning and their involvement should last up to the end of the whole process.

This situation leads to an important economical consequence, in fact on one side a certain budget can be allocated to noise abatement measures but on the other side existing resources allocated to other purposes could be optimized for noise reduction, for example some traffic reduction plans or air pollution plans.

CONSULTING THE PUBLIC

Another important aspect to consider is the information to the public. The END defines in article 3 the public as "one or more natural or legal person and, in accordance with national legislation or practice, their associations, organizations or groups". The public should be involved from the early stages of the planning about proposals for the plan accounting for the results of the participation. It also has to be informed about the decision taken. Consulting the public has a paramount importance; in fact there is a huge difference between noise exposure quantitatively computed with noise indicators and noise perception and annoyance.

The European community defines noise as "unwanted or harmful outdoor sound created by human activities including noise emitted by means of transport, road traffic, rail traffic, air traffic and from sites of industrial activity" [3]

Annoyance instead is "an emotional state connected to feelings of discomfort, anger, depression and helplessness". " [4]

The perception of noise is more related to the characteristics of noise rather than noise indicators. For example at the same sound pressure level road traffic is considered more annoying than rail traffic. Moreover a series of subjective factors influence the noise perception. For example age, social-economic background and attitude towards different means of transport. [2]

Consulting the public can help to define priorities for noise abatement and suggestions for measures to apply that might be different from those based only on quantitative measurement. Moreover it can also help to find solutions for necessary measures that are more easily accepted.

In fact awareness of the impact of noise on health and the relation between own behavior and noise generation can increase the general acceptance of the public of noise abatement measures.

CRITERIA TO IDENTIFY NOISE REDUCTION MEASURES

The action plan requires to identify critical areas where the intervention is needed. Thereafter, noise reduction measures for each specific area should be studied. There are several different measures that can be chosen, according to different criteria. These criteria are related to the particular situation treated and are necessary in order to make the selection process as clear as possible.

In the below are listed some criteria according to the recommendations from the SILENCE project: [2]

- Noise reduction effect :Even though the noise reduction for practical reasons is usually based on noise levels, the general aim must be to reduce the annoyance and to avoid health issues that noise exposure generates. So the number of people that benefit from the noise reduction might be more important than the effective noise level abatement. This generates several questions to be discussed when selecting abatement measures as for example if it is better a higher number of people benefiting from a lower noise reduction or vice versa.
- Positive or negative impact on other policy objectives. :In chapter 3.1 it is shown that the noise reduction policy has a great impact on other policies and inversely other policy objectives might impact on noise targets. Some examples are reported in the following table.

Other policy field	Positive impact	Negative impact
Air quality	Speed limits and HGV restrictions might reduce noise emissions as well as air pollution	Noise barriers might interfere with local air circulation, contributing to high concentrations of air pollutants
Road safety	Reducing the number of cars and HGVs might reduce noise and increase road safety	Road humps to reduce speed limits might increase noise.
Energy consumption	Less noisy driving stile usually save fuel	

Congestion	Smoothing traffic flow might reduce noise.	Night-time restriction for HGVs might lead to congestion in the early morning hours.

Table 0.1 - Examples of impacts on other policy objectives [2].

- Costs: Cost-benefit estimation can support decision-making and help prioritize between options. Of course it represents not an easy task. Two methods are the most used. The first method is called "stated preference" and it is based on people "willingness to pay" to reduce their noise exposure. The second method is "hedonic pricing" and it is based on price differences on the housing market as a result of noise exposure. These studies are complex and lead to very different results. However they point out the high benefit of noise reductions in monetary terms.
- Public acceptance and compliance: It is also important to consider the expected public acceptance because for many measures it is necessary for the fully effectiveness of the measure itself. This is the case of speed limit for example.

Criteria might differ from those listed previously, for example the Emilia Romagna Region guidelines suggest the following ones: [5]

- Effectiveness: Most of the solutions are effective only for a limited situation. For instance they can be effective only up to a certain height or up to a certain distance from the source. Thus they can be compatible or not with the issue they have to deal with.
- Durability: The durability of the solution might be too short to deal with the noise issue for the whole period of the action plan.
- Construction time: The time needed to construct the abatement measure (including the time to obtain authorizations) might be too long and might not fit with the deadlines of the action plan.
- Indirect limits: There can be environmental limits or conflicts that make the solution not affordable. Moreover only subjects different from those who propose the plan can adopt some typologies of intervention.

HIERARCHY OF INTERVENTIONS

Noise abatement strategies refer to four different categories:

a) Measures to avoid and reduce noise at its source.

b) Measures to reduce the propagation of noise.

c) Measures on the relative distance between source and receiver.

d) Measures to reduce noise at the receiver.

The hierarchy of interventions should follow this priority scale based on the principle of the source: [6]

I. Prevention to noise at source.

II. Reduction of noise along propagation path between noise source and receiver.

III. Receiver protection.

The principle of the source states that the study of noise abatement measures should start with the source. In the best case scenario the production of noise should not even happen. Acting on the source is the most effective type of intervention and also the most cost-effective one. If it is not possible, then measures should act on the propagation path between source and receiver and at the end on the receiver. This is due to the fact that measures on receiver improve the quality of the ambient indoor but do not change the situation outdoors, moreover some measures are not always effective, for example insulating windows is not effective when windows are open.

STRATEGIES TO AVOID AND ABAT NOISE AT ITS SOURCE

ROAD INFRASTRUCTURE

The noise generated by road infrastructure is generally composed by two elements: the rolling of the tire on the road pavement interaction and the propulsion of the engine. These two components have different source heights with respect to the road pavement and they depend on the velocity and on the drive pattern in different ways. For these reasons they need different noise reduction measures taking into account that:

- The noise generated by rolling is prevalent on propulsion noise after 40 km/h for light vehicles
- The noise generated by rolling never overcomes 40% of the total noise for heavy vehicles.
- Heavy vehicles produce more noise than light vehicles but this difference diminishes when the speed increases
- Accelerations produce more noise than constant speed or decelerations.

- The noise generated by each transit sums up energetically with those generated by the other vehicles (logarithmic sum) [5]

Studying traffic and the effect on noise production allows to determine criticalities of the road infrastructure and focus improvements. There are several measures to deal with the noise problem, many of them would also improve the situation under other points of view, for example air quality, traffic congestion, requalification of the territory and so on. Disadvantages are represented by the necessity of a global study of traffic management to get the real understanding of the situation and of the effectiveness of the analized measures. Some of the solutions are listed in the following.

REDUCING TRAFFIC VOLUME

Although the fact that the change of traffic volume has consequences on the noise levels, it is important to underline that a reduction of 50% of the number of vehicles will lead to a decrease of 3 dB of the noise levels. And while a change in sound pressure level of 1 dB(A) is barely audible, a decrease of 10 dB(A) is necessary to be perceived as a noise reduction of half. This means a reduction of vehicles to 10% of the original number of vehicles.

Reduction in traffic volume	**Reduction in noise (L_{Aeq})**
10 %	0.5 dB
20 %	1.0 dB
30 %	1.6 dB
40 %	2.2 dB
50 %	3.0 dB
75 %	6.0 dB

Table 0.1 - Relationship between reduction in traffic volume and reduction in noise level [2]

A reduction in traffic volume is effective in terms of noise reduction only if speeds are kept low and driving patterns do not change in a negative way. The reduction of traffic volume on a road will often mean an increase in speed because the vehicles can drive more freely, with harder acceleration and a different driving pattern that produces an increase of noise levels that counteracts the reduction firstly induced. Thus this solution may be applicable on minor roads coupled with other measures to move traffic on major roads. On major roads it is almost impossible to reduce noise levels reducing traffic, unless dealing with long-term planning aiming at moving people from cars to other modes of transport.

Measures to reduce traffic volume are giving priority to public transport and rerouting private vehicles, turning lanes into bus lanes, implementing low-emission zones or limited access zones, constructing new bypass roads etc. Besides most of these measures usually serve also other objectives: they will reduce the traffic slightly and they should be considered in a whole package of measures.

The costs vary with the measure adopted and the local situation. Signs for banning cost 300 EUR each, while the costs of a new bypass road amount to 10000000 EUR/km. [2]

BANS ON TRUCKS

A ban on trucks means limiting the access of trucks to specific roads or to a larger area. It can last all day, at nighttime or for a specific time period. This measure has little effects on noise levels but it is likely to reduce the number of noise peaks and limit annoyance of those living along the road. It should be considered if the effect of this measure is to shift traffic to another road or to shift the effect of noise to another day period, for example during morning hours if the ban regards night time. The measure also integrates air quality and road safety improvement. Noise levels have been reduced up to 6-7 dB but the results are strictly related to the context. Costs of signs are about 300 EUR each. If the ban has to be implemented for a large area additional measures as informing heavy vehicles drivers and implementing roads designated to trucks are necessary. [2]

REDUCING AND ENFORCING SPEED LIMITS

A feasible approach to reduce noise emissions especially in urban area is the reduction and the enforcing of speed limits. After 40km/h road noise depends on the mean velocities. For light vehicles an increase of 10 km/h of speed leads to an increase of 1.2 dB, while for heavy vehicles the same increase in speed leads to an increase of 1 db. Not only speed is important to control noise levels, but also for driving patterns and in particular accelerations. Thus to reduce noise emissions it is necessary to limit also accelerations. [5]

In general reducing the speed will also contribute to road safety and improved air quality. The speed reduction measure should lead to a sufficient decrease of speed without driving change to a lower gear, which could increase noise levels. Another problem is to make drivers comply with the speed reduction measures: studies show that reducing speed limits of, for example, 10km/h through static signs has no evident effect on actual driving behavior.

Variable signs for posting speed limits have proved to be more effective; in fact they increase driver awareness, but on the other hand this effect may decrease if the signs are more widely used and have become less noticeable to the drivers. The reduction of speed varies case by case and so does the reduction of noise. Reductions up to 3 dB LAeq can be attended.

Static signs are comparably cheap, about 300 EUR per sign, while variable signs are quite cost-intensive. [2]

Other possible measures to control velocities are listed in the following.

AUTOMATIC TRAFFIC CONTROL

Automatic traffic control (ATC) is a measure to make speed limits effective. There are different types of automatic controls classified according to the functioning. The most used ones are those composed by two cells, when the vehicle passes through the signal of the first cell activated the recording. The recording stops when the vehicle passes through the signal of second cell. Knowing the distance between cells, velocity is computed. There are also other types of controls that require to be used by operators. It should be considered that with fixed cameras there might be the tendency to induce a bad driving behavior, decreasing velocity in proximity of the checkpoints and increasing it between cameras. This generates accelerations and decelerations and increases noise levels and annoyance; moreover they might be dangerous for other drivers. To avoid this problem radar system calculating the average speed might be effective if known by drivers.

This measure shows no effect on daytime if the traffic itself keeps the speed limited, but it can lead to a decrease of 2 dB during nighttime in proximity of the ATC. The installation of this measure is quite expensive, but costs can be covered by fines.

HUMPS AND CUSHIONS

Vertical deflections as humps and cushions are measures for speed reduction with consequences on noise levels. The velocity at which the vehicle can pass the obstacle diminishes with the increase of the hump height. The height varies from about 5 to 15 cm, with a length from 0.3 to 3 m, the latter case representing the humps usually implied for residential areas. In addition of diminishing the speed, and so reducing the overall noise emitted by the vehicles, they also might lead to a reduction in traffic level inducing the drivers to prefer other routes. A proper design is important: spacing should maintain a steady driving pattern, if it is too large there could be decelerations and accelerations that may increase noise level and annoyance. Moreover drivers do not always care about these obstacles and, if speed is not properly reduced, impulsive noise is generated, especially in the case of heavy vehicles.

While the design plays a small role to the noise emission for light vehicles as long as it matches the desired speed regardless of the type of hump or cushions, the design gains importance for heavy vehicle. In fact in this case round-top humps and narrow cushions, up to 1.7 m wide, have to be preferred, keeping the speed under 25 km/h; otherwise they are useless or even worsen. In residential roads flat-top humps and wide cushions may lead to significant increases, up to 10 dB, of noise levels for heavy vehicles. [2]

The costs of this measure are limited, but some drawbacks are represented by the slowing down of traffic flow with possible problems to viability.

CHICANES

Chicanes reduce the width of a street in order to make drivers slow down, moreover they can give additional space, for example for trees or bicycle parking. The effects in terms of noise reduction depend on the achieved average speed, on the new driving pattern and on traffic volumes and compositions. However this measure needs to be studied carefully because negative effects are likely to be generated.

Chicanes can be single lane or to lane, drivers have to slow down to check for traffic coming from the opposite side, especially heavy vehicles, and vehicles coming from the two driving direction might need to stop entirely. This generates a speed reduction but it can also generate an increase of noise levels due to different driving pattern with decelerations, braking and accelerations. The design of a chicane may vary greatly and so its costs but a mean value can be set around 2000 EUR/m². [2]

JUNCTION DESIGN

Junctions, ordinary intersections with or without traffic light and roundabouts, have influence on traffic noise emissions. The effectiveness of these measures depends on the traffic and on the layout but the relationship between these parameters and noise reduction are still unclear. It is certain, however, that noise levels are diminished if the speed is reduced and the driving pattern gets more even.

Roundabouts are particular intersections that have been largely implied in many different context; thanks to their particular features they lead to the diminishing of the velocities and of conflicts between vehicles, the generation of more even traffic flows without waste of time, the possibility for vehicles, and in particular heavy vehicles, to inverse the driving direction in complete security. Noise levels are consequently reduced and moreover air quality and visual aspect of the intersection are improved. Disadvantages are the impossibility to have preferential lanes, increasing of risk for motorcycles and long deviations for pedestrian crossing.

Mini-roundabouts are roundabouts with very limited dimensions that, when properly designed, may lead to noise reductions up to 4 dB. The design should consider that the presence of an overrun areas of paving stones to allow large trucks to pass may induce car drivers to drive there at high speed, increasing annoyance. This type of measure should be studied further. The mean value of the cost for this measure is 7500 EUR for the construction of the mini-roundabout and 2000 EUR/m² for redesigning streets. [2]

REDESIGNING STREET SPACE

Redesigning street space is a measure to noise abatement inducing drivers to slow down intuitively. It can improve the visual impression of the street, it can support less noisy transport modes by attributing more space to cyclists and pedestrians, improving also road safety. In this way drivers will adapt their driving speed to the local context, they will have the impression of not being privileged making them reducing speed. A possible measure is narrowing the lanes giving more space to pedestrians and cyclists or parking. Planting trees or flowers will create the impression of a narrow road with no need of actually reducing the lane width). Other possible measures are: narrowing lanes at junctions, reducing the strict separation between lanes etc.

The effects in terms of noise reduction have to be calculated for each scenario according to the achieved average speed, the driving pattern, the traffic volume and composition. This type of measure not only reduces noise levels but also reduces annoyance. The mean cost is about 2000 EUR/m² for redesigning streets. [2]

CALMING GREEN WAVES

Green waves are coordinated signalization at a number of intersection to allow traffic in a certain direction to flow without having to stop at red lights. This measure leads to smoother driving and most likely slower noise emissions of about 4 dB at intersections. On the other hand studies show also an increase of 3 dB due to increased traffic flow and velocity, so choosing the proper design parameters according to local road network conditions is very important for the effectiveness of this measure. [2]

LOW NOISE ROAD SURFACES

Road surfaces influence the generation of noise. Relevant characteristics of roads are: texture of the surface, texture pattern and degree of porosity. A number of mechanisms generate noise from vehicles passing on road surface:

a) The engine and the transmission system generate noise of frequencies smaller than 1000 Hz. This noise propagates both directly from the vehicles and is reflected by the road surface. Thus if the surface absorbs to some degree the total noise might be reduced. This is called propulsion noise;

b) The tire/pavement interaction is called rolling noise, and at mean and high velocities this is the main noise mechanism. It can be sub-divided in other mechanisms.;

- The aerodynamic noise generated by air pumping, when tire rolls air is forced out or sucked in between the rubber blocks of the tire. The frequency range is between 1000 and 3000 Hz. If the surface is porous the noise can be reduced and if the surface is open but not porous the air pumping noise will be also reduced;
- The vibration of the tire surface produces noise, when the rubber bocks of the tire hit the stone at the top of the pavement, the tire vibrates. Frequencies of noise generated are between 300 and 2000 Hz. If the pavement structure is smooth or elastic vibrations are reduced;
- Acoustical horn is formed in the driving direction between the curved structure of the tire and the road surface. This horn amplifies the noise generated by the tire/pavement interaction. If the pavement absorbs noise the amplification is reduced.

Noise reducing pavements act on rolling noise and if they have noise absorbing capacity they limit also propulsion noise and propagation through reflection. They can be used in the ongoing pavement maintenance process and thus be a simple and cheap noise abatement measure.

In general results are about 2-4 dB of reduction for low velocities and 3-6 dB for high velocities.[4]

Compared to other noise abatement measures, like barriers or soundproof windows, the costs for this solution are relatively low. Moreover this measure does not need compliance of drivers to be efficient and in most case this kind of surfaces reduces the rolling resistance leading to a decrease of fuel consumption. On the other side to achieve the best results accuracy in the laying process and regular maintenance and repair are necessary. [2]

Low-noise road surfaces should have the following properties: [2]

- Low level of unevenness and discontinuities. Singularities like manhole covers humps and bumps, tram crossing etc. are relevant and should be taken into account;
- Low excitation of tire vibrations by surface texture;
- Sufficient air ventilation under the tire contact patch;
- High void content to achieve sound absorption;
- Adapted dynamic stiffness.

The choice between different solutions depends also on the durability of the acoustic reduction effectiveness. Limits are imposed also by the necessity of road safety.

Good road surface maintenance is necessary in order to keep the noise levels as low as possible, especially in case of low noise surfaces. An effective maintenance implies a frequent and consistent monitoring of the properties of the pavement. Suitable indicators that can be used to evaluate the noise performances are direct acoustic parameters that should always be used and indirect measures that are important to determine the causes of performance degradation.

Maintenance actions should account for preserving the low-noise feature despite speed and costs and the following rules apply:

- Repairs should be carried out with the same material as the original in order to maintain the surface structure;
- Porous surfaces require early enough cleaning especially in urban area with low velocities where self-cleaning cannot be assumed;
- Two-layers surfaces require the replacement of the top layer to solve the problem of clogging.

Other conventional maintenance actions should be avoided:

- Milling or grinding the top layer destroys the original top layer making the measure ineffective;
- Surface treatments including sealing would invalidate the noise reduction.

Regular maintenance might lead to additional costs, however compared to other noise abatement measures the total costs for low-noise pavements are relatively low.

There are several solutions and many of them are still studied and implemented, here are reported some of the most common solutions.

POROUS ASPHALTS SINGLE LAYER

Porous asphalt is one of the most common low noise road surfaces. This solution reduces the noise generated by air pumping effect and the propagation of noise through reflection on the pavement. It presents an open structure with about 20-25% of air void in-built, higher than that of normal asphalts. The high percentage of voids allows the dissipation of rolling noise. It has a higher absorbing potential than thin layers, moreover it drains water, up to 20l/min, increasing tire adherence and road safety.

Studies show that for highways single layer surfaces achieve the best reduction with a maximum size of aggregates of 8 mm a built-in air void of 20-23% and thickness of 40 mm, while for urban roads single layer is not suitable. [2] After only one year in urban roads the noise abatement passes from about 3 dB to about 1 dB**.** [6]

This asphalt shows several disadvantages: costs are about 70% higher than those for normal asphalts, durability is low, mainly because of clogging; winter maintenance is difficult because salt is rapidly washed away and not effective and there are difficulties in repairing. [6]

Porous asphalts need to be cleaned regularly, for example twice a year, using high pressure water otherwise the pore gets clogged with dust with a loss of effectiveness after about 2 years. Thus this measure is recommended only for speeds greater than 60 km/h and homogeneous traffic flows. It has an average noise reduction of 3-4 dB on highways with a decrease of 0.4 dB per year for light vehicles and 0.2 dB for heavy vehicles at high speeds and 0.9 dB at low speeds. [2]

POROUS ASPHALTS DOUBLE LAYER

This type of porous asphalt is more suitable for urban roads. The top layer reflects the dust but lets the sound pass and it should have a thickness of about 2 cm and a maximum aggregate size of 8 mm, the bottom layer absorbs the sound and it should have a thickness of about 4 cm and an aggregate size of 16 to 22 mm. [6] This type of asphalt has auto-cleaning properties: vehicles passing, especially heavy ones, make in pressure the air inside voids that exits from the pores cleaning dusts and residuals. The noise reduction is elevated but costs are high, about 30 Eur/m^2 more than normal asphalt. Studies show that with this solution an initial noise reduction of 4 dB or more was achieved; however to maintain effectiveness, as one layer porous asphalt, this pavement needs to be cleaned regularly. For this reason in urban areas thin layer surfaces are normally to be preferred. [2]

11.1.1.1 THIN LAYER ASPHALTS

Thin layer asphalt is another type of low-noise surface composed by different bituminous layers with a maximum thickness of 3 cm and a small size of the aggregates, 4-8 mm. This solution leads to an initial noise reduction of 3 dB but, although no special maintenance has to be performed, the effectiveness of the noise reduction decrease of about 0.1 dB per year. The costs for this measure are about the same as the price of ordinary pavements, relating to the conditions of the old pavement of the road. [2]

PAVING BLOCKS

A new low noise solution is the use of paving blocks that can be used in alternative of cobblestones. While paving stones usually increase the noise levels of 3-5 dB due to their uneven surface structure, this measure does not lead to the same disadvantage. Paving blocks have about the same noise emission as ordinary pavement, but they keep at the same time a better visual appearance. [2]

INFLUENCING DRIVER BEHAVIOR

Driver behavior has a high influence on the emitted noise. Low engine speed without acceleration achieves significant reduction of the propulsion noise of vehicles.

There is a relationship between acceleration and noise for cars. Studies show that for speeds around 30 km/h the average noise increase due to acceleration is 2 dB, while for speeds around 50 km/h the increase is 1-1.5 dB. Less aggressive driving styles are believed to reduce the noise of about 5 dB for cars and 7 dB for motorcycles. [2] Thus it is clear that modifying driver behavior would lead to effective noise reduction. The limit of this measure is the fact that health effects related to noise do not always convince the public. However other aspects induced by a more passive driving behavior like fuel saving and reducing air pollution may be more convincing for drivers.

LESS NOISY VEHICLES

This measure implies replacing not only old vehicles with new, and so less noisy, ones, but also the type of propulsion, for instance electric vehicles instead of fuel vehicles. There is also the possibility to replace vehicles with others, especially studied to reduce noise emissions. In the below some examples are reported.

RENEWAL OF PUBLIC TRANSPORT FLEET

New vehicles are generally less noisy than old ones. Thus renewing the fleet can significantly influence noise abatement. Vehicles have to be renewed anyway so this solution does not lead to any additional cost and could lead to benefits also in terms of air pollutants, energy consumption and road safety.

ELECTRIC PUBLIC VEHICLES

This type of vehicles have recently been implemented especially in urban city centers, to furnish a public transport in areas closed to traffic, to preserve air quality and to reduce noise levels. The main disadvantages are the elevated costs, limited autonomy and limited capacity.

LOW NOISE WASTE COLLECTION VEHICLES

Waste collection can be particularly annoying especially because it is usually done during nighttime or in the early morning. Replacing old vehicles with new ones might lead to noise reduction up to 25 dB(A).

In Gothenborg-Sweden traditional waste collection vehicles have been replaced with special ones based on hybrid technology that combines natural gas and batteries. Vehicles move with gas engine but the collection, system works with batteries. Despite the high noise potential and also the improvement of air quality, doubts remain about the battery life. Costs are from 22000 to 32000 EUR. [2]

CHECK ON NOISY VEHICLES

Some vehicles are equipped with replaced silencers and most of them are illegal and much noisier than the original ones. This is more common for cars and motorcycles with respect to trucks. Besides the contribution to the total noise level, motorcycles raise additional annoyance because of the noise peaks. Thus controls are necessary and this measure could not only reduce noise level but also annoyance. However roadside enforcements checks often fail because of costs and the necessity of experienced staff. Usually stationary noise test close to the exhaust pipes have proven to be rather inefficient, while drive-by tests similar to the type approval test would be much more efficient.

LOW-NOISE DELIVERY VEHICLES

This measure allows to shift deliveries from day-time, when delivery vehicles parking on the road may cause congestion, to night-time, without arising noise emissions and annoyance. By using adequate equipment and training operators on low-noise operations, noise level might be kept low. Studies suggest maximum sound equivalent level LAeq of 60 dB(A). [2] Costs might be elevated but they can be compensated by financial advantages for shop owners.

RAIL INFRASTRUCTURE

Rail infrastructure noise is composed by:

- Rolling noise due to wheel-track interaction;
- Noise due to propulsion engine;
- Aerodynamic noise.

The influence that each noise component has depends on several factors as speed, number of wagons, quality of supports. For diesel engine the propulsion noise is prevalent, while for electric trains rolling noise is the main source if velocities are between 60 and 300 km/h, otherwise the other components are predominant. Freight trains are in general noisier than passenger trains. Here are reported some possible noise reduction measures.

LESS NOISY RAIL MATERIAL

Old fatigued elements can be replaced with new and less noisy ones. For example disk brakes on passenger trains avoid the deterioration of wheels with a noise reduction up to 8 dB. [5] In case of trams new vehicles have noise emissions 10 dB(A) less than old ones (about 30 years old). Thus even in the case of gradual renewal the noise reduction is effective. [2]

REDUCTION OF TRAFFIC FLOW

Similarly to the case of road infrastructure the reduction of traffic flow is effective only if it is significant. The same rules listed previously applied. However in case of flow reduction the effects on the service provided for a determined section are noticeable. Thus this measure is applicable only in very limited cases.

REDUCTION OF VEHICLE SPEED

A reduction of the train speed of 30 % will lead to a noise levels abatement of 3 dB, while a reduction of 50 % will lead to an improvement of 6 dB. [5] This measure should be studied carefully; in fact speed reduction heavily impact on the carrying capacity of the railway line.

INTERVENTION ON THE WHEEL-RAIL INTERFACE

Periodic maintenance is a necessary measure both on wheels and on trucks. Damaged wheel ruin tracks and these ruin wheels of other trains and so on. Wheels deteriorates after 7000-8000 km covered and wheel maintenance let to a noise reduction up to 10 dB(A); for wheels with disk brakes the problem arises after 10000 km or more and the noise reduction due to maintenance is about 2 dB(A). [5] Tracks need to be periodically polished and welded joints have to be preferred because they are less noisy.

INTERVENTION ON THE INFRASTUCTURE

In ordinary sections some solutions to reduce noise are:

- Stone ballasts thanks to the presence of voids reduce noise up to 2 dB with respect to concrete one;
- The use of rigid sleepers of double-blocks concrete;
- The anchorage of the rail to the sleeper;
- Dampers to the rails;
- Integrated obstacles to propagations (low barriers, embedded rails etc.).

Particular attention should be paid for viaduct and bridges where noise emissions are incremented because of the vibration of the structure, especially for steel structures. Intervention on the infrastructure to reduce this noise might be expensive and complicated but this measure can be affordable in case of new structures. One solution is to design parapets that work as noise barrier, paying attention not to propagate sound.

Railway cuttings might reduce noise even though they are not very effective for low frequencies. Vertical walls can be provided to absorbing covering (cladding). In natural cuttings the slope lawn absorbs some noise. Vegetation can be effective if it covers 10-15m perpendicularly to the infrastructure.

RAILWAY AND TRAM DEPOT

The location of railway and tram depots in proximity of residential areas arises noise annoyance, linked to several different types of noise generated in the structures. The annoyance caused by each source varies with noise level, thus the first step is to identify the different sources and identify the most relevant in the local situation. Choosing intelligent locations for each source might already improve the situation, as well as allocating activities in-line diminishing the number of movements. Moreover reduction measures at the source might be implemented, like reducing roughness of tracks or lubrication of tracks in curves.

AIRPORT INFRASTRUCTURE

Airport infrastructure noise can be divided between flying noise and noise produced on land. Flying noise is prevalent for extension and intensity, but it is directional and affects a limited portion of ground. Noise produced on ground is generated by operational and maintenance activities, moving along landing strip, engine check and auxiliary power units, refueling etc.

Noise reduction measures that can be implemented are listed below.

LESS NOISY VEHICLES

The International Civil Aviation Organization (ICAO) established requirements for airplanes. Aircraft are categorized according to noise emissions on the base of the isophone amplitude on land during taking off and landing. New airplane should satisfy requirements and old ones are progressively dismissed according to this classification.

OPERATIVE RESTRICTIONS

European Directive 2002/30/CE [7] states the possibility to introduce operative restrictions for each airport limiting the access to airplanes that overcome certain noise thresholds. This measure however can be taken into account only in extreme cases and gradually.

TAKING OFF AND LANDING PROCEDURES

Low-noise procedures consist in methodologies to apply by operators during taking off and landing to minimize noise on land and to protect population in the nearby of the airport. They consist of optimizing the projections of air routes according to the position of urban areas, in special taking off and landing procedures and in the respective vertical profiles.

INDUSTRIAL INFRASTRUCTURE

The European Directive 96/61/EC [8] implies the adoption for companies of the Best Available Technologies (BAT), that are defined by the European Community on the base of exchanges of information between experts of member States, industries and environmental organizations. Data are collected and periodically updated. In general industrial noise is generated by several types of sources so noise abatement measures should be studied for the specific case considered.

MEASURES TO REDUCE THE PROPAGATION OF NOISE

BARRIERS

When direct measures at the source are not possible it is necessary to consider passive solutions. Noise barriers represent the most common solution; they are represented by a screening of material between source and receiver. When a barrier is inserted the noise from the source is divided into two components: the part of noise that passes through the barrier that is limited by the absorbing capacity of the screen, and the part that bypasses the barrier. The line connecting source and the top edge of the barrier and the line connecting the top edge of the barrier and the receiver form an angle. The bigger is this angle the higher is the attenuation of the noise that bypass the barrier.

Noise barriers have significant impact to reduce noise propagation along roads and railways. This solution is effective also for areas outside the buildings like balconies and gardens. Some drawbacks are represented by the elevated costs, the average cost of barriers is 300 Eur/m^2, and their impact on the environment: barriers affect the visual scene of the area, they increase difficulties in crossing the roads and might impact on local air quality blocking the air flow.

The main requirements are the dimensions of the barrier that should be sufficiently high and long. Barrier can be made by a wide range of materials with different characteristics of absorption and reflection of sound. The average insertion loss of a barrier depends on several factors such as geometry, position with respect to source and receiver. These parameters are defined during design and if they are not correct they cannot be compensated by the choice of materials. The insertion loss depends also on the climate and on the specific site. Moreover to compute insertion loss multiple reflections on ground, on barrier edges and other surfaces should be accounted. In theory this measure would lead to a reduction of 15 dB(A) of noise levels, although in practice, if the buildings are close to the line source, the reduction is between 5 and 10 dB(A). [2] The closer the barrier it is to the source the more effective it is.

Depending on their shape and on the material used, barriers offer different levels of noise reduction. A lot of different solutions both for materials and for shape are currently studied. Barriers panels can be simply reflecting or absorbing. Absorbing barriers have absorbing elements facing the traffic side, reducing the reflected sound and improving the positive impact of the screen. These barriers are commonly used, but they are more expensive than simple barriers. Other possible solutions are:

- Capped barriers are specially shaped at the top section to reduce the sound waves at the top;
- Angled and dispersive barriers through tilted walls or contoured surfaces reflect the sound away from the sensitive receivers.

Particular attention should be paid if receivers are located on both sides of the barrier. In this case barriers with panels with high noise absorption capacity on the source side have to be preferred to avoid reflections.

It is important to underline that there are several limitation in the choice of the barrier as security prescriptions, landscape and visual limitations and so on.

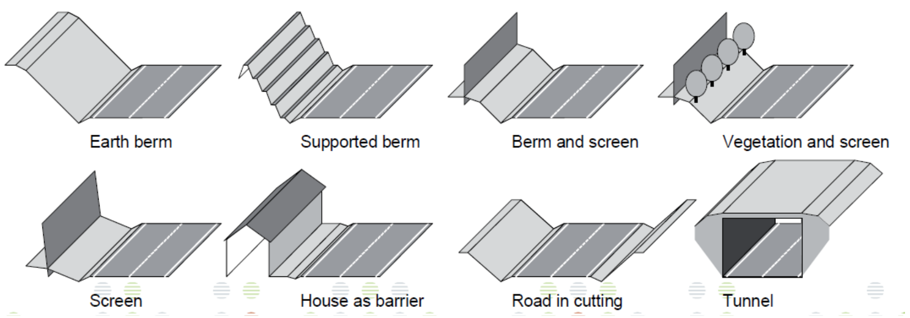

Figure 0.1- Types of noise barriers. [2]

EMBANKMENTS

This noise reduction measure consists in a layered embankment covered by lawn or bushes. The main advantages of this measure are the low environmental and landscape impact and the high effectiveness. Noise abatement can reach 20 dB. [6] Disadvantages are the necessity of space that limits the possibility to imply and the elevated costs of construction and maintenance.

VEGETATION WALLS

Vegetation cannot be considered equivalent to acoustic barriers unless it is high, dense, compact and large. The noise reduction is approximately 1 dB(A) per 10-15 m depth of planting. [6] However the impact is more psychological and esthetical. Screening the sight of the source reduces awareness of the noise and the annoyance.

TUNNELS

Tunnels are realized with a technology similar to that of noise barriers. They can lead to a reduction of noise levels up to 25 dB and also improve air quality. They represent the most effective means of noise screening but also the most expensive one, moreover they have a huge impact on landscape. They are hardly used for specific noise abatement purposes.

MEASURES ON THE RELATIVE DISTANCE BETWEEN SOURCE AND RECEIVER

LAND USE PLANNING

At the early stages of land use planning there is a high noise reduction potential. Land use plans relevance on noise abatement is often underestimated because decisions taken will not directly affect the exposure of dwellers but noise reduction becomes measurable only when concrete development plans are implemented. Typical tools to avoid noise conflicts are land use plans or zoning plans that indicate quiet spaces to be protected against noise immissions. Another possibility is allocating land use in a way that there is a sufficient distance between future noise emissions and sensitive areas, however this solution might generate additional traffic noise. The plans can regard the whole city or the district or only a part of it and they can be used for the development of a new neighborhoods or the redevelopment of existing areas. The plans depend on the resources available like space, terrain, zone policy, population density etc. In the following some possibilities are listed. [2]

NOISE COMPATIBLE BUILDINGS AS NOISE BARRIERS

A very cost-effective land use planning measure is to allocate noise compatible buildings like shops and offices between the noise source, road or railway usually, and the residential buildings. This solution has the advantage to let an intensive land use but requires a sufficient demand for space for noise compatible buildings.

Figure 0.1 - Buildings as noise barriers [2]

BUILDING DESIGN

Building design can be implemented to reduce indoor noise levels. In particular some solution are listed below.

a) The structure of the residential buildings can be designed in such a way that the propagation of noise is reduced. Terraced house reduce the sound propagation and offer at least on quiet façade. This does not happen for detached or semi-detached houses.

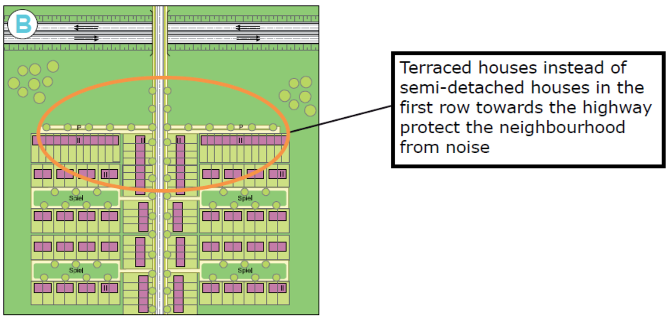

Figure 0.2 - Structure of residential building that reduces noise propagation [2]

b) Shed and garages can form a courtyard giving one quiet façade to the buildings.

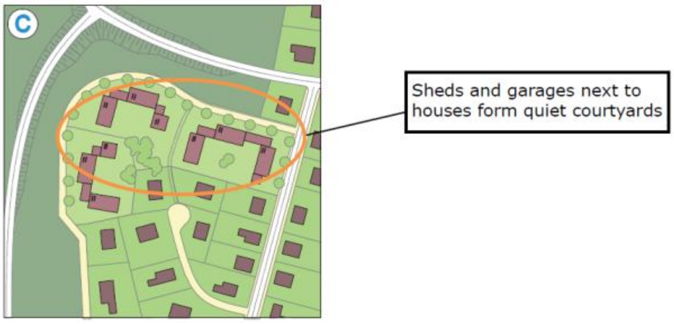

Figure 0.3 - Shed and garage as barrier [2]

c) Room plan can be designed allocating the less noise sensitive rooms such as kitchens, bathrooms, stairways and storages close to the source and forming a barrier to noise sensitive rooms like bedrooms, that should be placed towards the quiet façade.

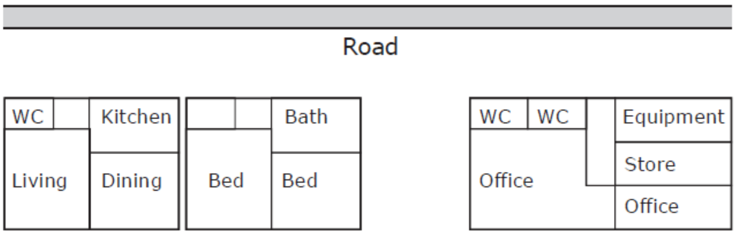

Figure 0.4 - Room plan to protect sensitive rooms [1]

d) Shape and orientation of buildings should be planned considering both the impact on indoor noise level and the impact on other buildings in proximity. Sound reflected in façade might cause additional annoyance.

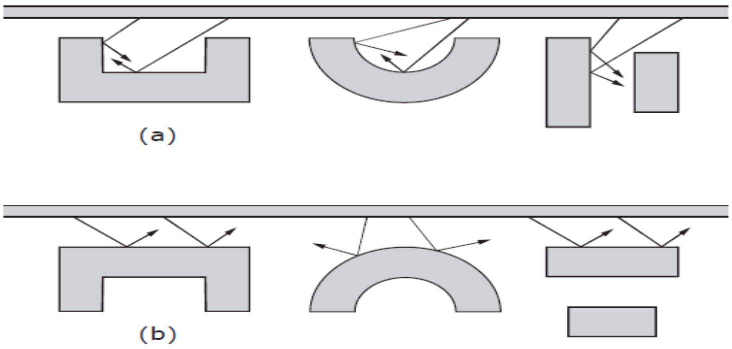

Figure 0.5 - Shapes and orientation of buildings [2]

Windows should be oriented away from the noise source and they could be protected with wing walls.

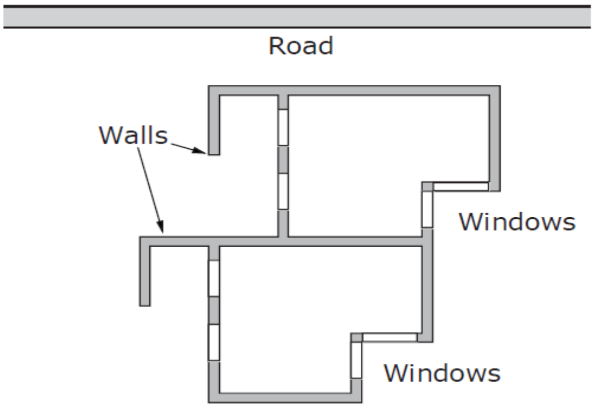

Figure 0.6 - Wing walls to protect windows [2]

Balconies also offer a noise protection of the range of 5 to 14 dB depending on geometrical parameters such as the width of the windows, the orientation, the depth of the balcony and the height of the boundary walls. The advantage of this solution is that no additional costs are required. The underside of the balconies should be designed to reflect sound away from the façades or be covered with noise absorbing material.

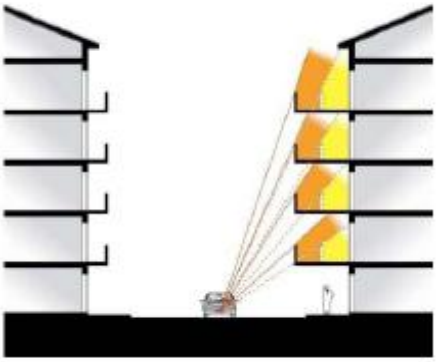

Figure 0.7 - Balconies screening [6]

DESIGN OF PARKS AND GREEN SPACES

This measure allows to reduce negative impact of noise if there is no opportunity to achieve an adequate noise level in the entire green area. The following recommendation should apply:

- Areas for noise sensitive activities should be placed as far as possible from the noise source, in case it is not possible railway noise source should be preferred with respect to road noise source because the latter is considered more annoying;
- Areas dedicated to communications should be carefully protected due to the fact that communication is early disturbed by noise;

- Sport activities are the least noise sensitive, thus they can be placed in the areas closest to the noise source.

ALLOCATION OF BUILDINGS IN COMBINATION WITH NOISE BARRIERS

As mentioned before noise barriers work in function of the height of the building. A good measure to implement this solution effectiveness is to allocate low-rise buildings closer to the source, this type of building in fact is easier to protect with the screening, while high-rise buildings should be allocated further from the noise source. In this way they can exploit the longer distance from the source.

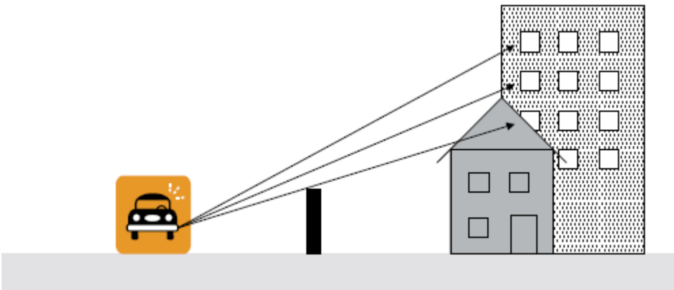

Figure 0.8 - Buildings in combination with noise barriers [2]

DISTANCE

Although placing distance between the noise source and the receiver is the most obvious solution, it should be considered that doubling the distance leads to a reduction by 3 to 5 dB depending on ground attenuation. Costs and also realization time are often elevated. Thus this measure is practicable for new areas and should be considered at the early stages of the planning process.

For linear source distance between source and receiver can be obtained through the moving of the source or the burying of the source. Bypass roads are another example of the moving away of the source, while the moving of the receiver is very rare and used in case of airports.

PLANNING NEW ROUTES FOR ROADS AND RAILWAY LINES

Noise from two different sources does not sum up arithmetically but energetically, that is to say with a logarithmic sum. Thus in planning new routes a good solution might be to place them close to already existing noise source. The noise level will increase little while the creation of new noise in a quiet area is avoided.

MEASURES TO REDUCE NOISE AT THE RECEIVER

BUILDING INSULATION

Sound insulation for dwellings is the last option if other measures at the source and over propagation path are insufficient. A high noise reduction can be achieved exactly where it is needed and it can be linked to thermal insulation which reduces also energy consumptions. Nevertheless this measure is effective only indoors and at certain conditions, for example sound insulated windows have impact only if closed. These measures can also be applied when it is necessary to protect sensitive buildings in an area where the noise conditions are acceptable for the other receivers. Costs are quite elevated if compared to other measures. However for new buildings where high thermal insulation standards are required, additional costs will be low.

INTERVENTIONS ON ACOUSTIC BRIDGES

Openings are responsible for the main part of the noise entering from outside to the inside of the building.

Windows, doors, air vents, exhaust pipe etc. need to be studied in relation to their noise insulation level, that is about 25-30 dB for well constructed items and up to 40 dB to special items with elevated costs. [5]

SOUND INSULATED WINDOWS

Sound insulated windows are the main solution for building insulation. Modern windows with double panes achieve a sound reduction of about 30 dB. [2] However the total noise level inside the dwelling depends also on walls and doors insulation. Moreover sound insulated windows reduce noise only when closed. To solve this problem other solutions have been studied like double panes windows with special ventilation systems.

AIR VENTS INSULATION

Openings for air vent highly affect the effectiveness of building noise insulation. In fact these represent the preferential path for noise immissions from outdoors to indoors. Special systems for air vents insulations are available, they elongate the noise path inside the pipes reducing noise immissions. The costs are moderate and the installation is simple.

OBSCURING ELEMENTS INSULATION

In order not to affect noise insulation, obscuring systems should be properly designed. In particular rolling shutter casing needs a correct installation with appropriate seals. Better acoustic performances are obtained for casing in high density materials such as timber panels of thickness greater than 15 mm. Metal sheet casing thickness should be greater than 1 mm. This system works better when casing is located inside the wall, with inspection door on the bottom.

INTERVENTIONS ON WALLS

If intervention on noise bridges is insufficient this solution is applicable. It consists in covering walls with a noise-insulating layer that can be placed outside or inside of the building according to the type of insulation chosen. Effectiveness and costs of the measure depend on the material chosen, on the existing wall and on the interaction between various elements.

INTERVENTIONS ON ROOFS

This measure is generally associated with airport noise due to flights over the building. The solutions regard roofing and false ceilings and in general the lower or the upper surface according to the chosen type.

Roof gardens are particular measures in case of plane roofs. The solution presents several advantages for acoustic and thermal insulation.

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[4] Delibera della Giunta Regionale del 23/09/2013, n°1339, D.Lgs 194/2005 "Attuazione della DIR 2002/49/CE relativa alla determinazione e alla gestione del rumore ambientale"- Approvazione delle Linee Guida per l'elaborazione dei Piani di azione relativi alle strade ed agli agglomerati della regione Emilia-Romagna".

[5] UNI 11327:2009 appendix f

[6] HUSH Harmonization for Urban noise reduction Strategies for Homogeneous action plans, In progress report. Action n. 5 http://www.hush-project.eu

[7] Directive 2002/30/EC of the European Parliament and of the Council of 26 March 2002 on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Community airports.

[8] Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control.